Appendix to report:

SBJ-33-C5-OON-22-RE-013-APPC

K12 - SHIP IMPACT, GLOBAL ASSESSMENT

Appendix title:

APPENDIX C – COMPLEMENTARY RESULTS

Contract no:	18/91094
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CONCEPT DEVELOPMENT FLOATING BRIDGE E39 BJØRNAFJORDEN

Norconsult
DR. TECHN. OLAV OLSEN
Prodtex IFE Pure Logic HEYERDAHL ARKITEKTER AS H&BB MIKO MARINE AS BUKSÉR OG BERGING FORCE TECHNOLOGY SWERIM

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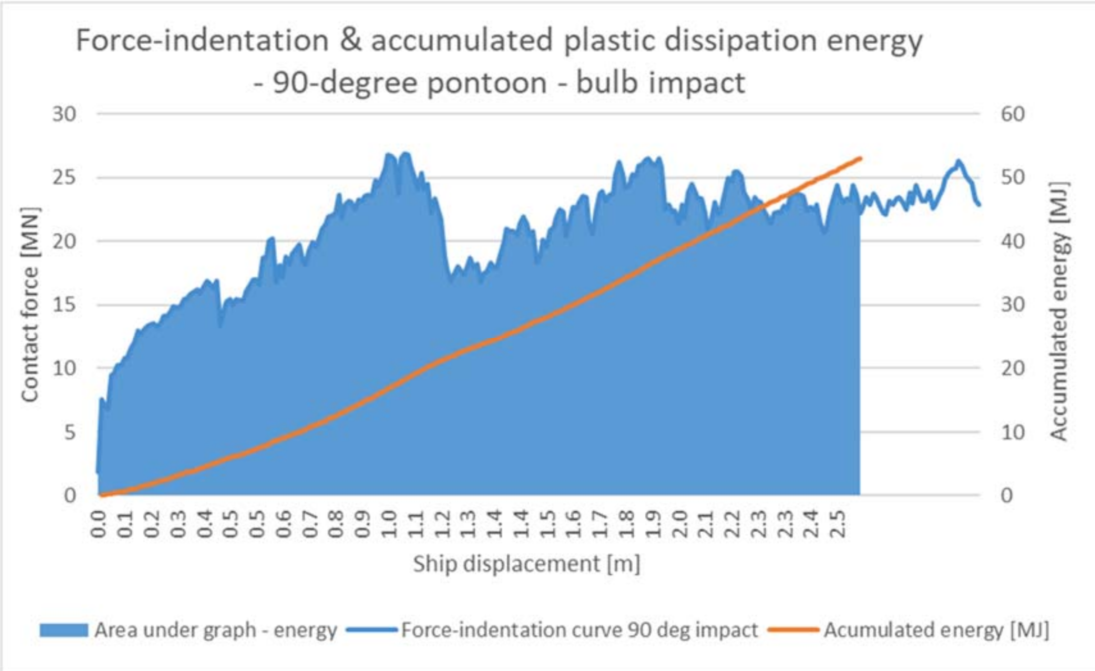
C.1 Sideway impact – section 3.2.3

The sideway impact near the ship navigation channel has a total kinetic energy of 53 MJ. For the remaining pontoons the impact has a total kinetic energy of 13 MJ.

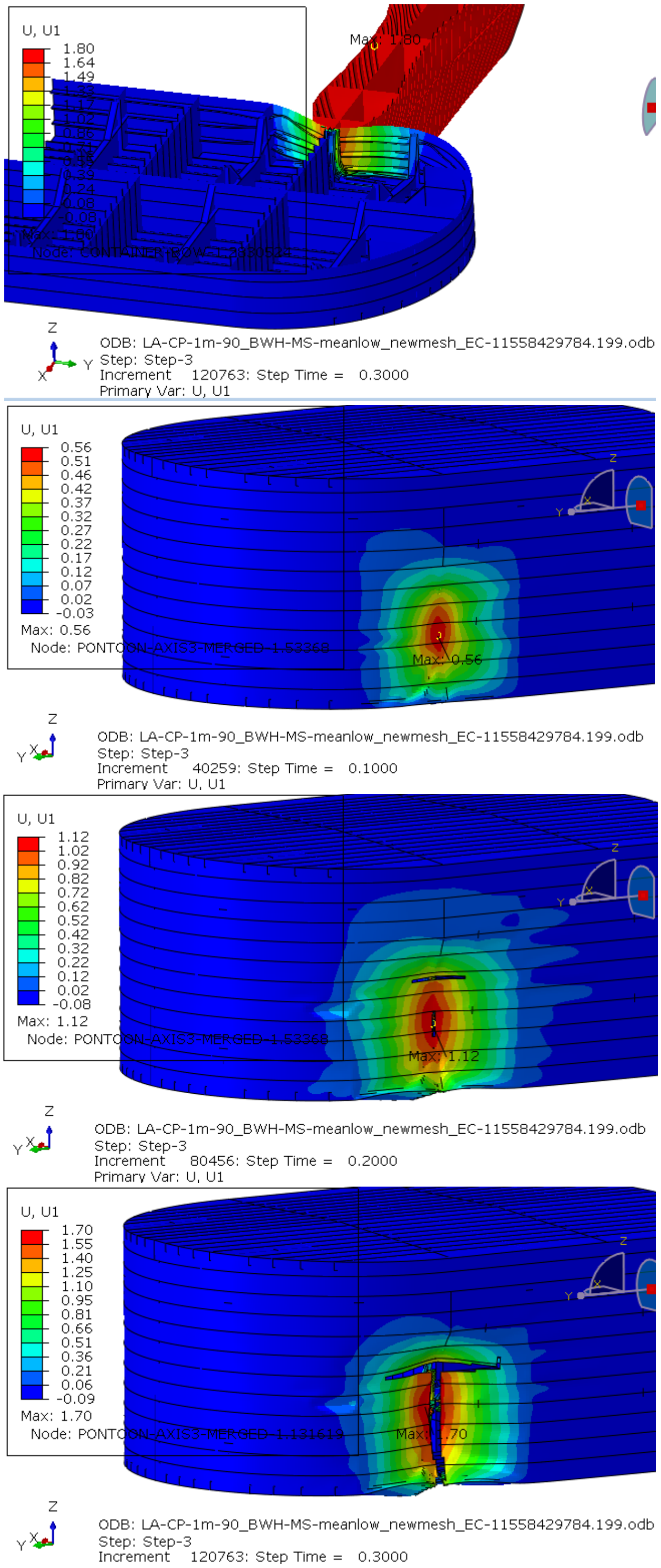
Based on the bulb-pontoon impact there has been made some considerations of possible outcomes from the sideway impact. Based on the force indentation curve obtain from the local analysis, see section 7.1 in "SBJ-33-C5-OON-22-RE-015-K12 - Ship impact, Pontoons and columns" [1], maximum indentation at 53 MJ is 2.6 m. See Figure C-1. This given the conservative assumption that all the deformation happens in the pontoon, not the ship.



> *Figure C-1 Indentation in pontoon at 53 MJ plastic dissipation.*

The impact area is small compared to the scenario where the broadside hits the pontoon. Given a maximum indentation of 2.6 m, maximum two compartments can be filled with water and this is not a governing load case.

To explore a more likely outcome of the sideway impact the fracture mechanisms are studied. The initiation of first fracture happens at approximately 1 m indentation, see Figure C-2. This means the 13 MJ-impacts on the remaining pontoons are not expected to cause any fracture in the pontoons.



> *Figure C-2 Initiation of first fracture in pontoon at 90-degree impact.*

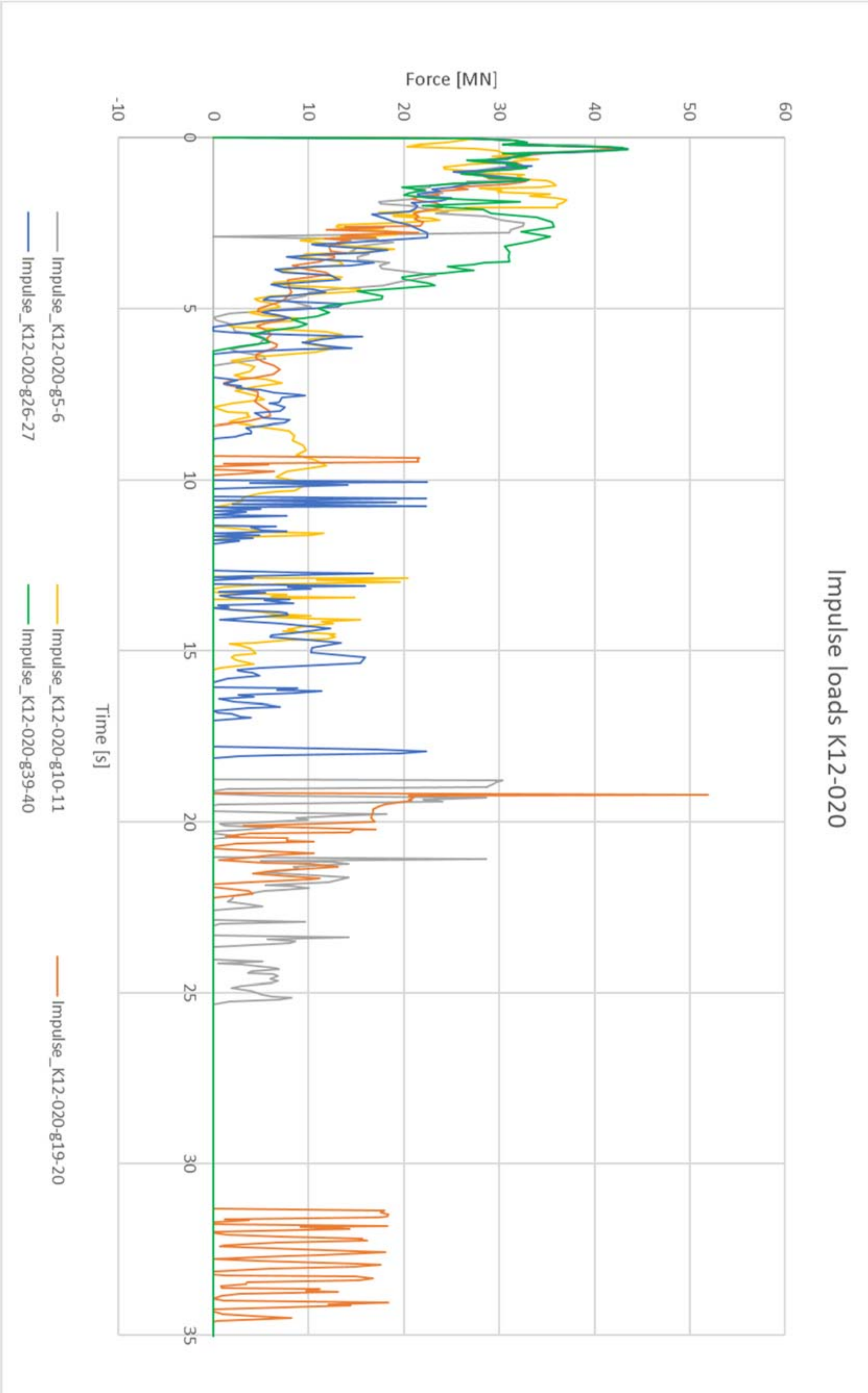
In a hit near the waterline on the pontoon wall the pontoon can probably handle deformations of this size in a quite large area. This makes it likely that the pontoon will not fracture and take in water in a "clean" sideway impact, as the impact area will be much larger and there is no bulb to penetrate the pontoon skin. In a "clean" hit along the top edge of the pontoon wall the pontoon can probably take less deformations before first fracture, but probably it can dissipate more energy due to a larger amount of "activated" steel. In less clean hits, where the sideway collision comes in at a larger angle, the damage will be more local like the bulb-pontoon impact, and water filling of maximum two compartments must be expected.

The worst-case impact for the water filling of compartments is probably where a head-on ship in high speed glances off the pontoon long side, but rips the pontoon open with an anchor or other equipment hanging along the side – like the KNM Helge Ingstad accident.

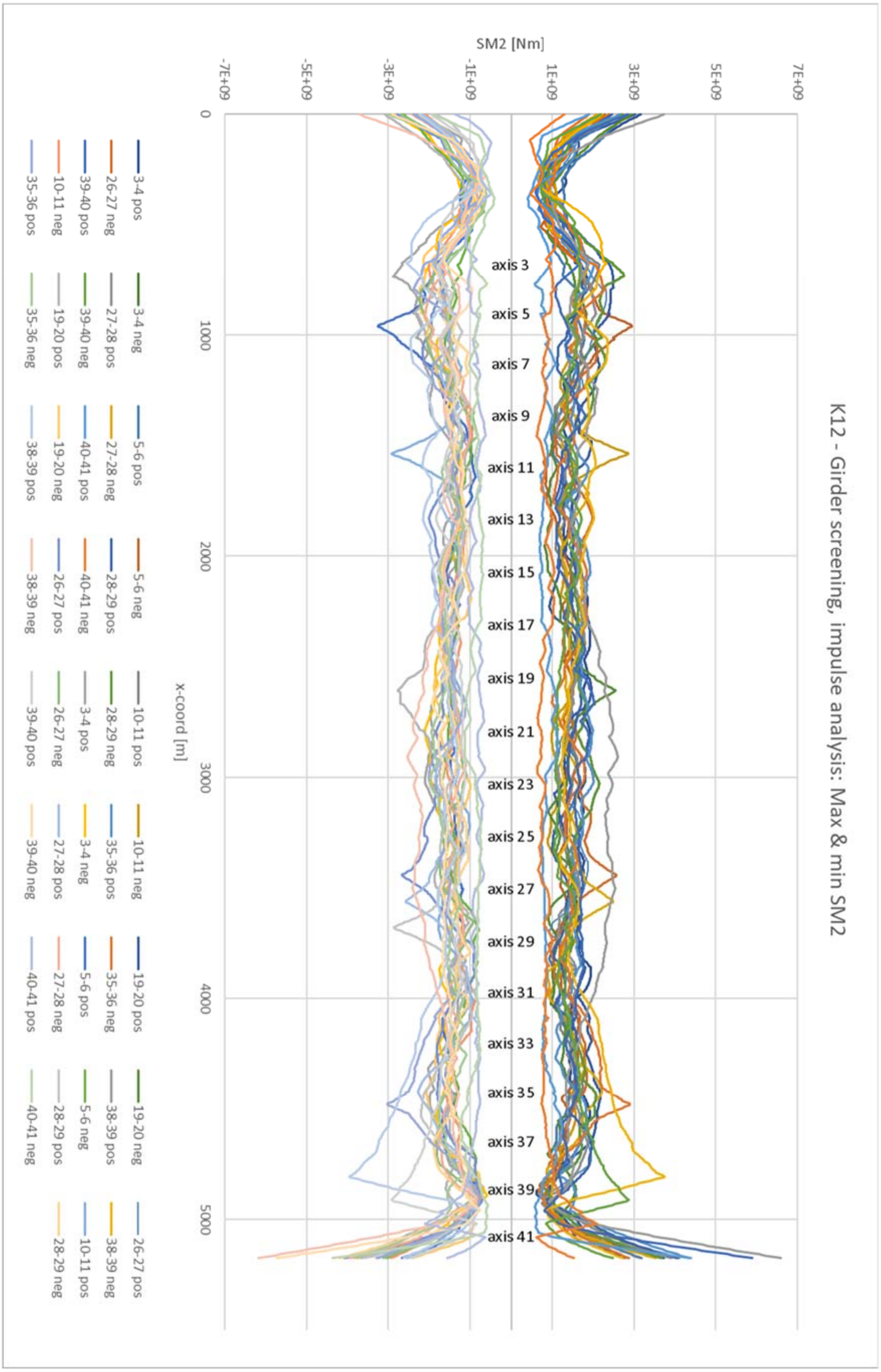
C.2 Screening analysis

Additional information is given here, such as extended figures, more readable figures etc.

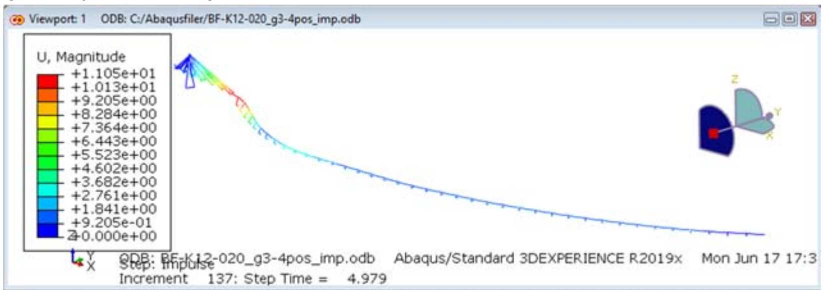
Impulse load gained from connector analysis:

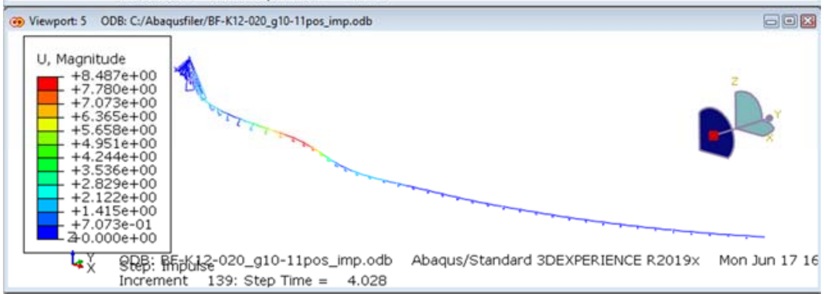


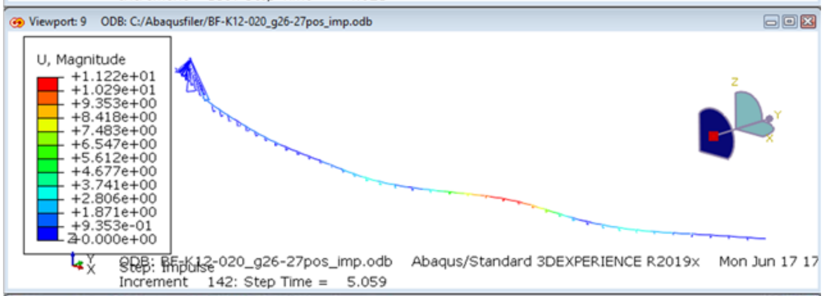
Maximum and minimum strong axis bending moment in girder, all impulse cases:

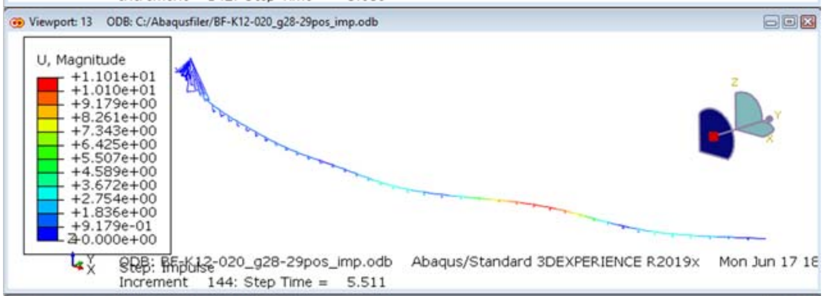


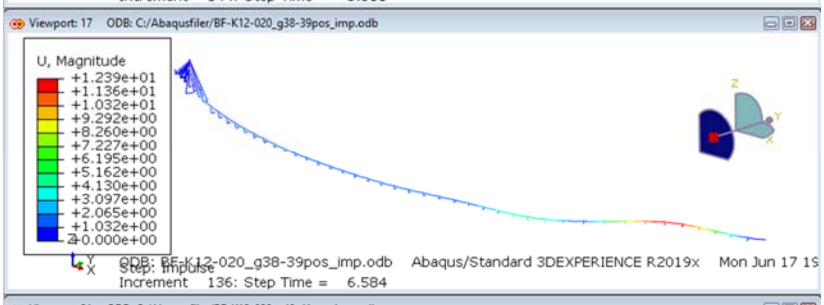
Displacement of bridge a few seconds into the impact – to show the direction of the impact (all impact cases):

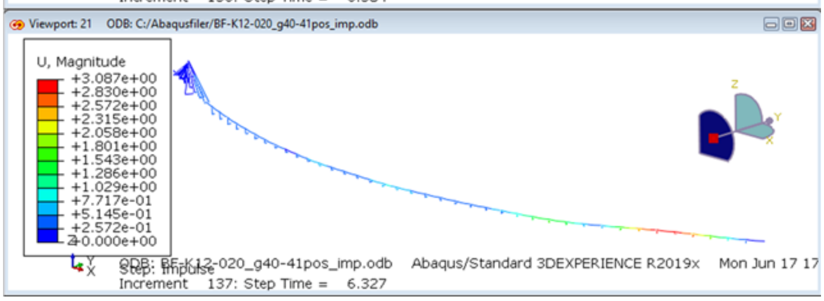


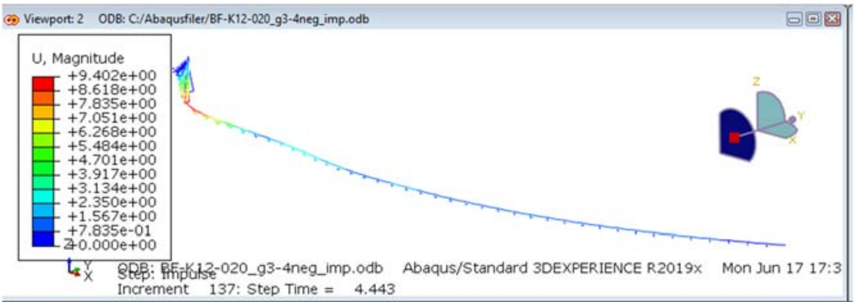








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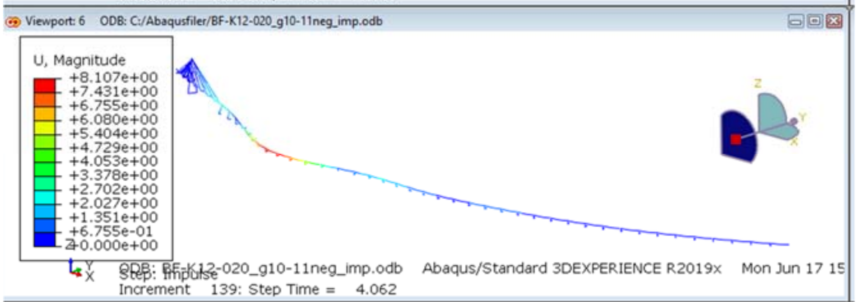
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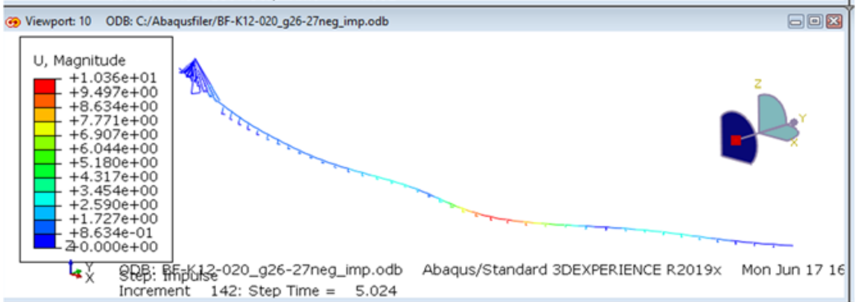
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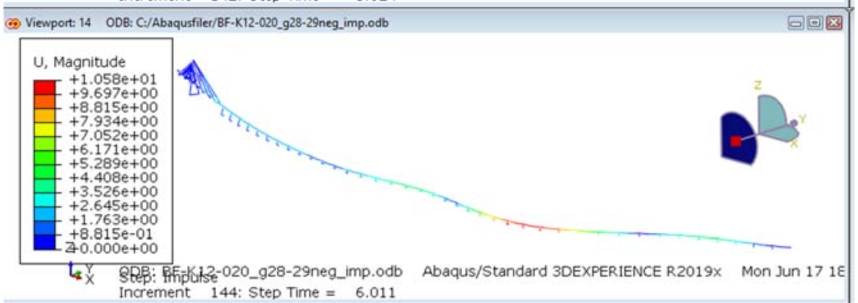
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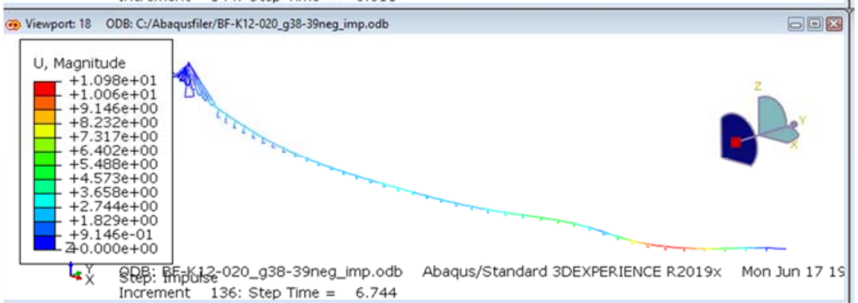
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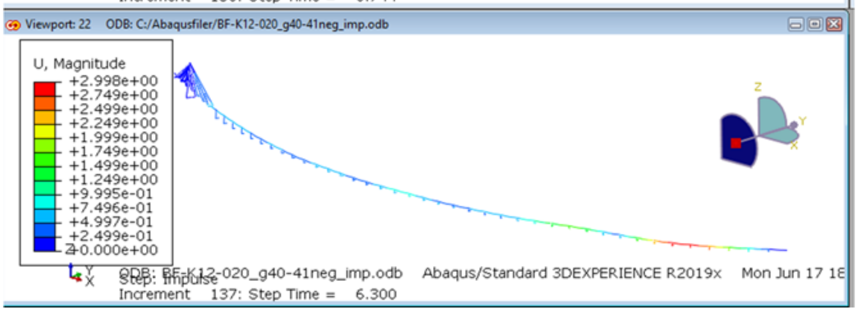
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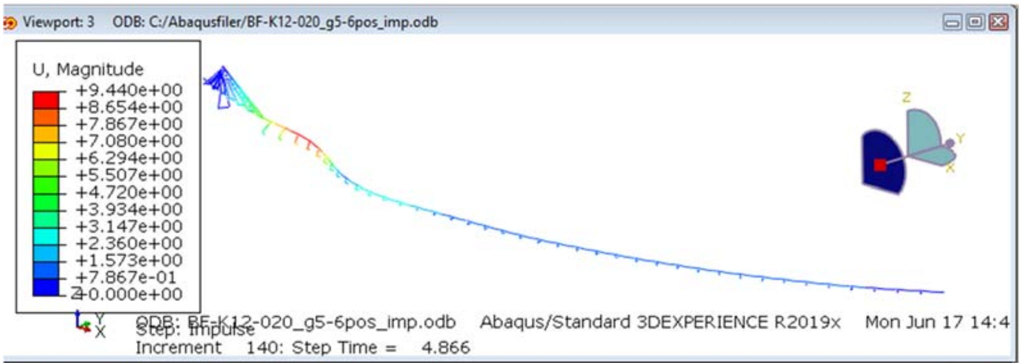
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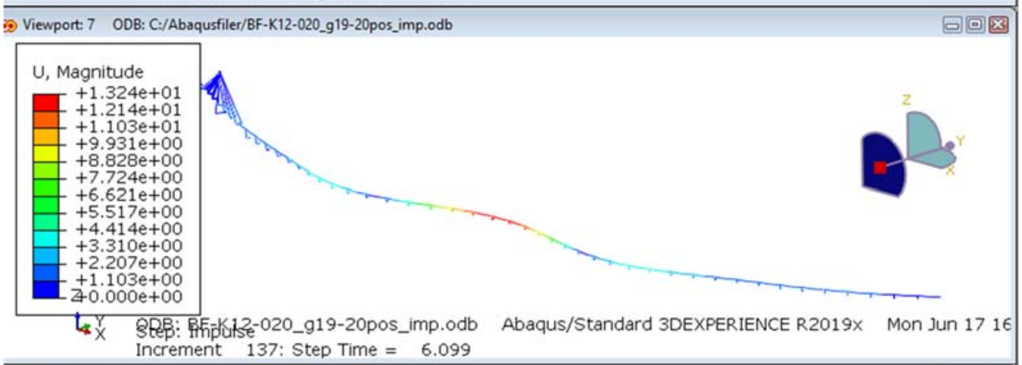
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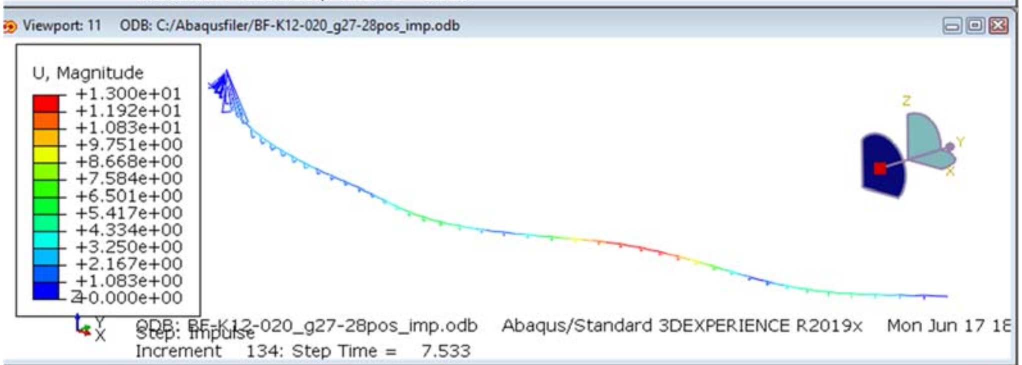
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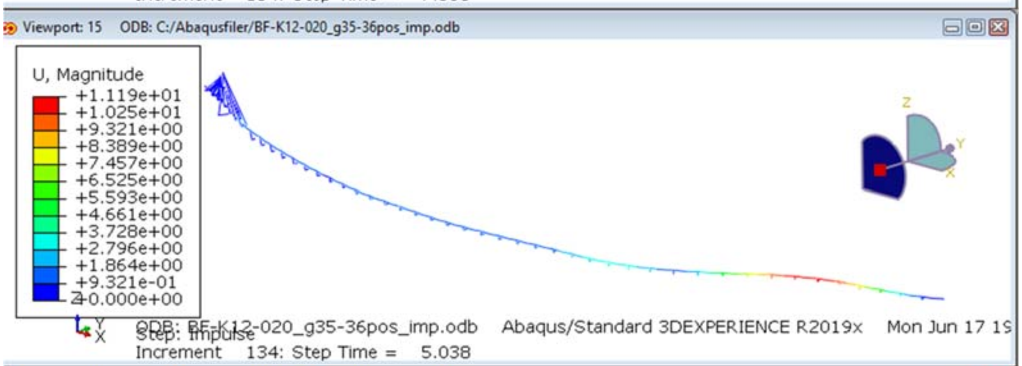
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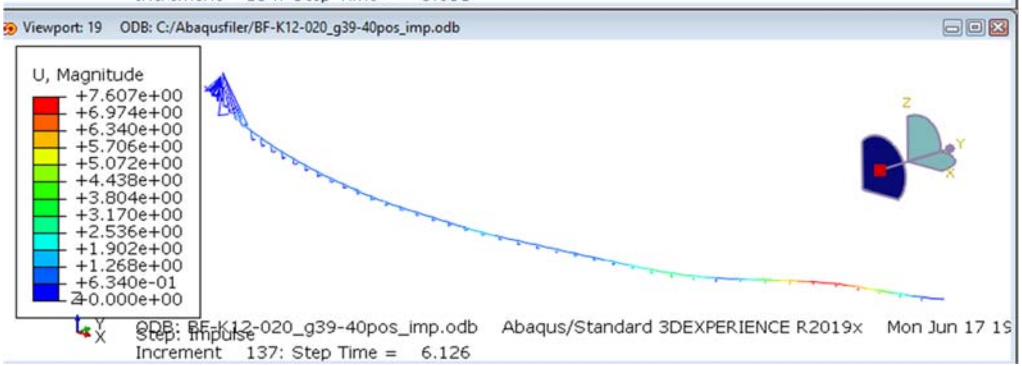
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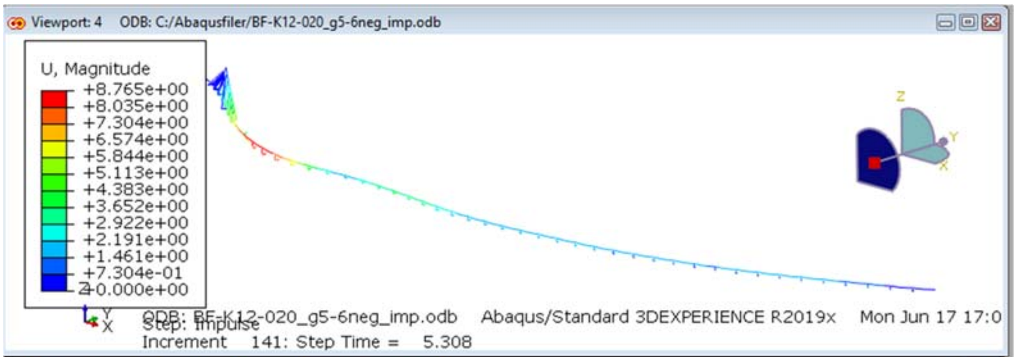
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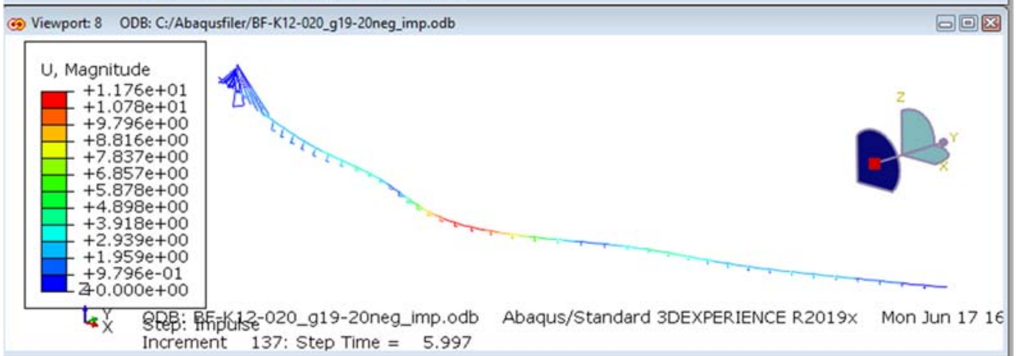
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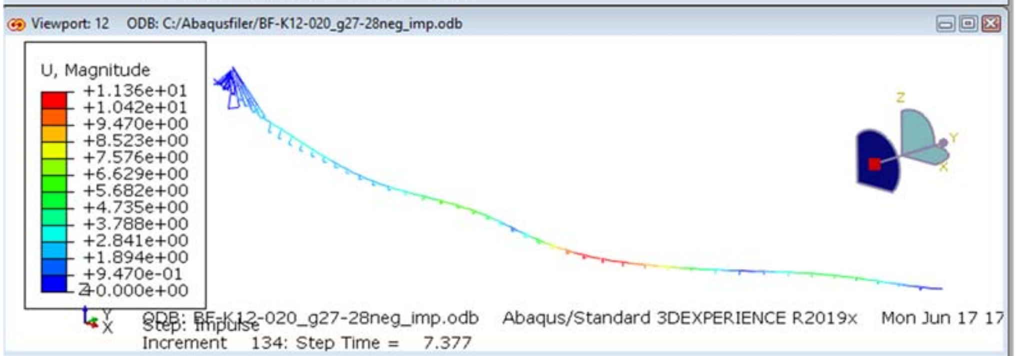
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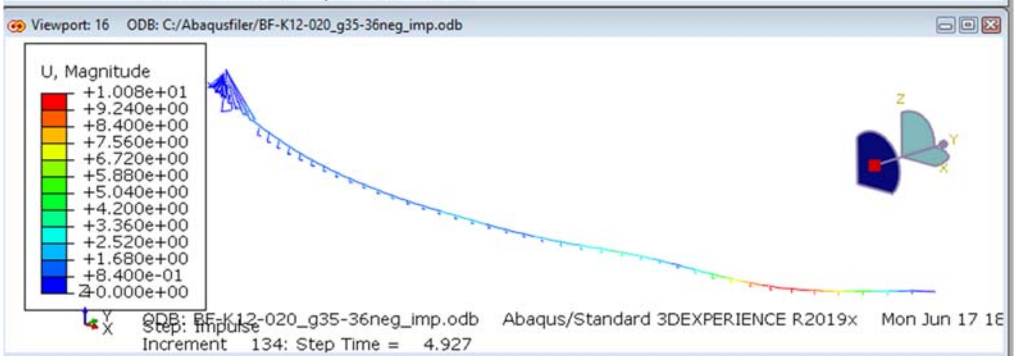
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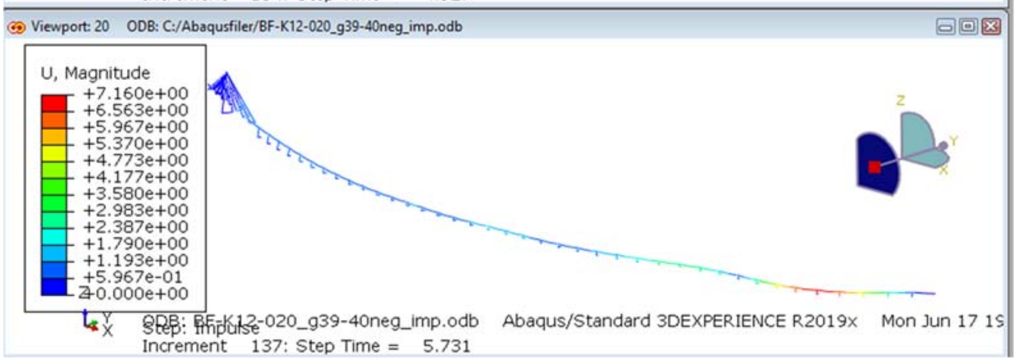
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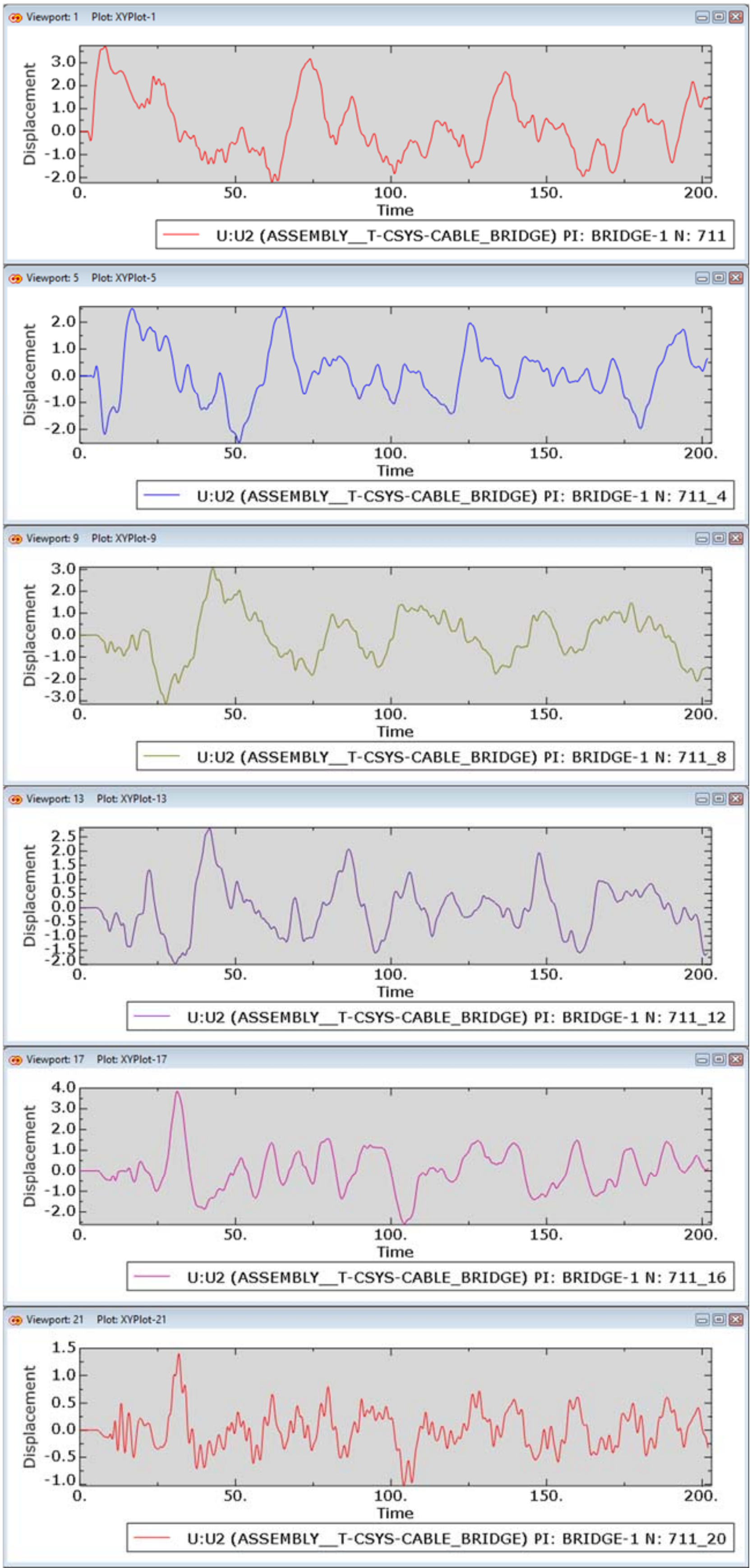
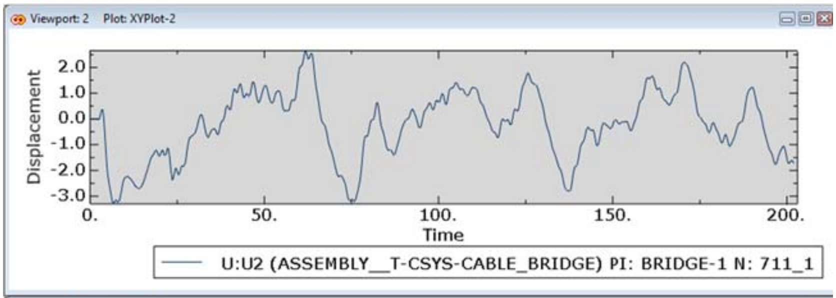
Transverse displacement of girder at landtower:

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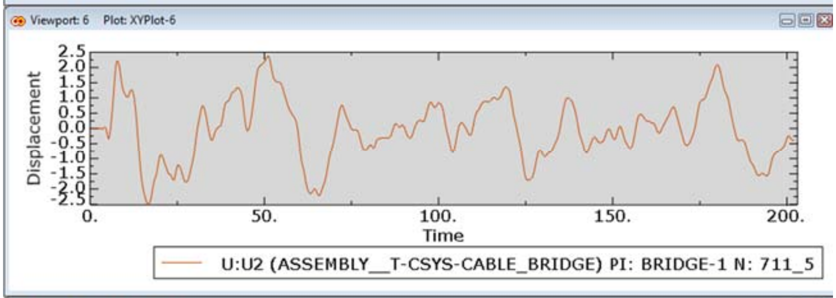
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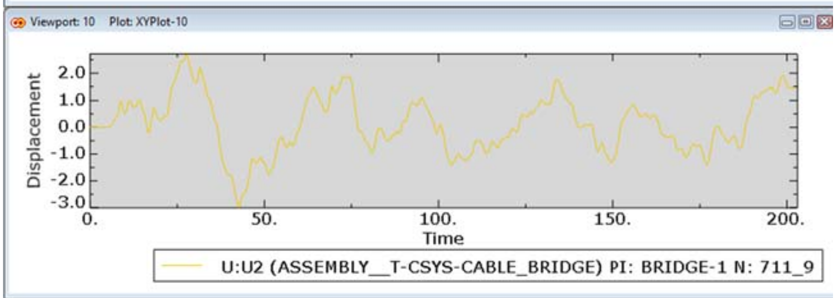
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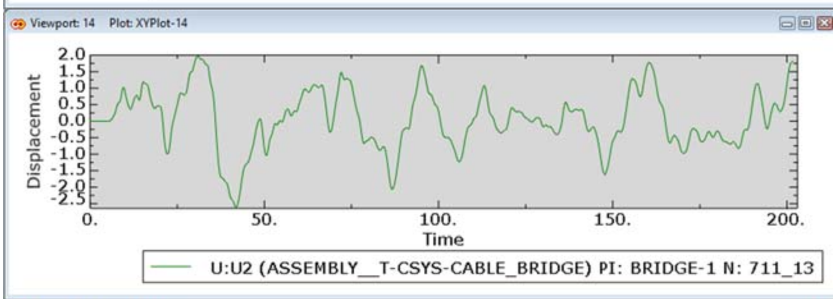
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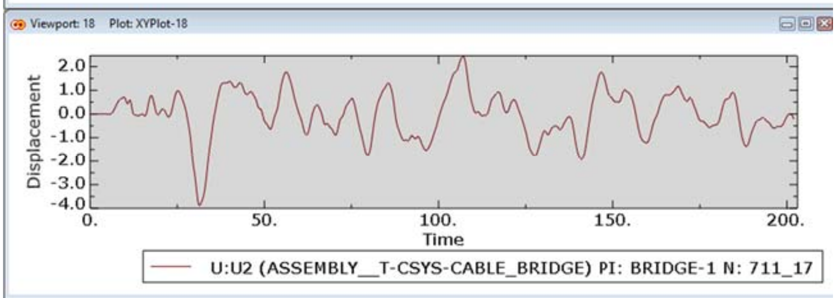
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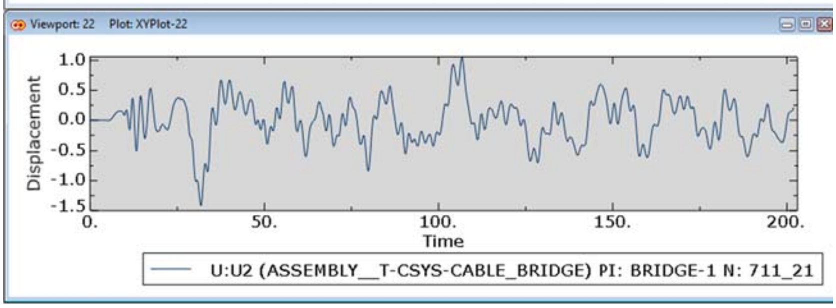
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Time
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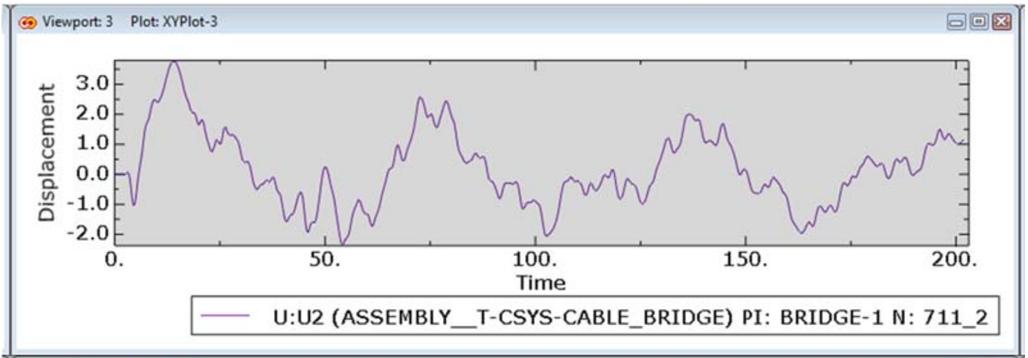
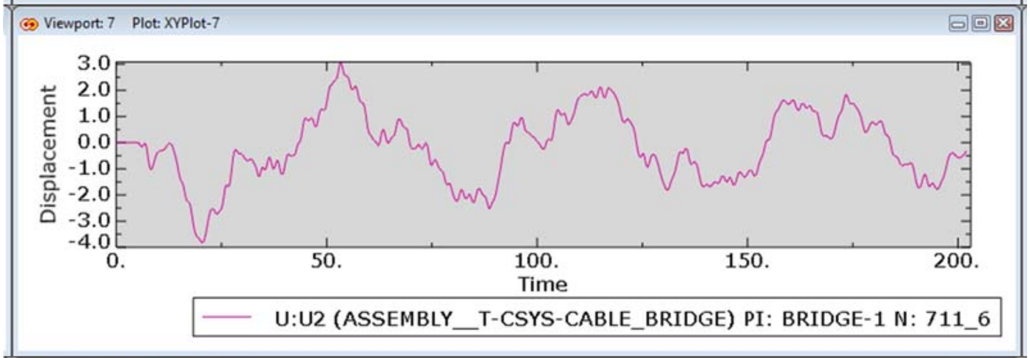
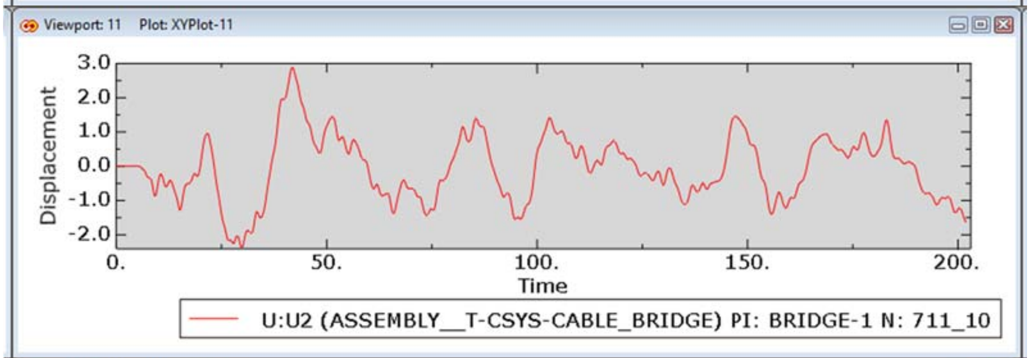
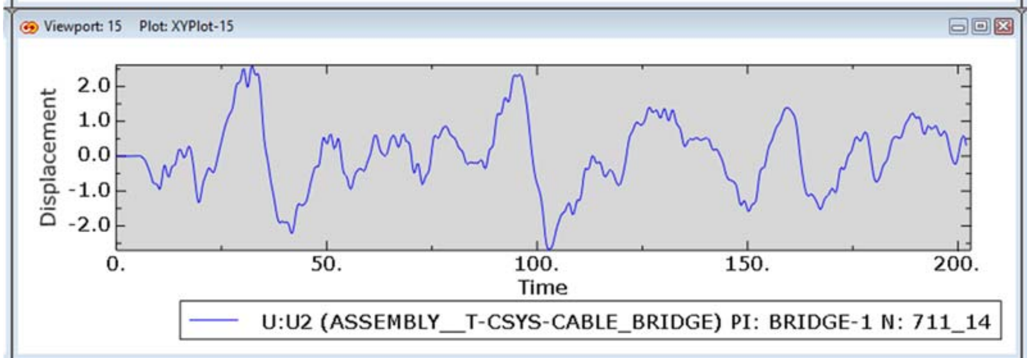
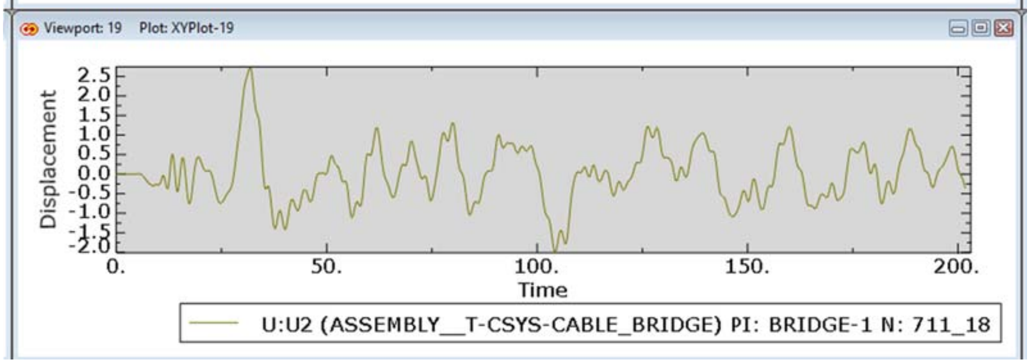
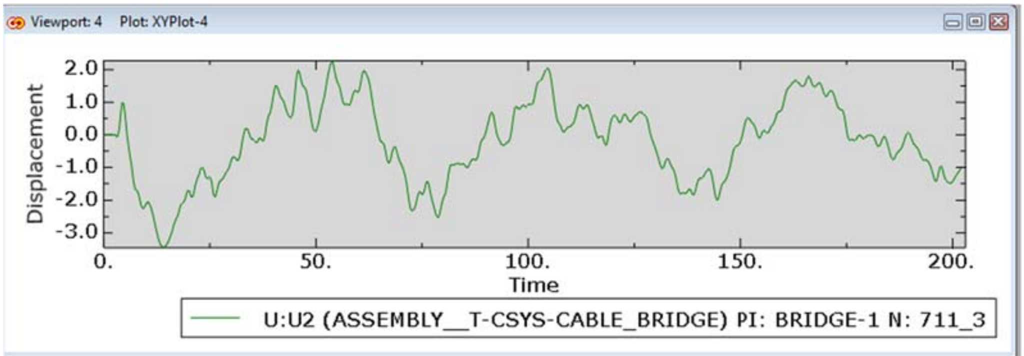

Viewport: 3 Plot: XYPlot-3
Displacement
3.0
2.0
1.0
0.0
-1.0
-2.0
0.
50.
100.
150.
200.
Time
U:U2 (ASSEMBLY__T-CSYS-CABLE_BRIDGE) PI: BRIDGE-1 N: 711_2

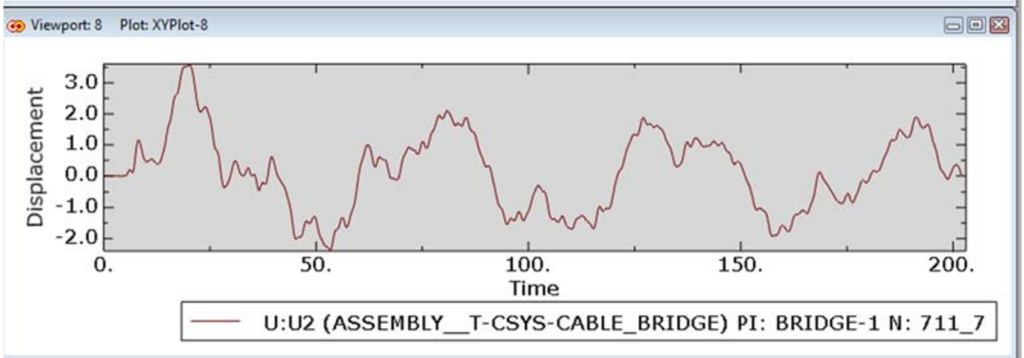

Viewport: 7 Plot: XYPlot-7
Displacement
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
0.
50.
100.
150.
200.
Time
U:U2 (ASSEMBLY__T-CSYS-CABLE_BRIDGE) PI: BRIDGE-1 N: 711_6

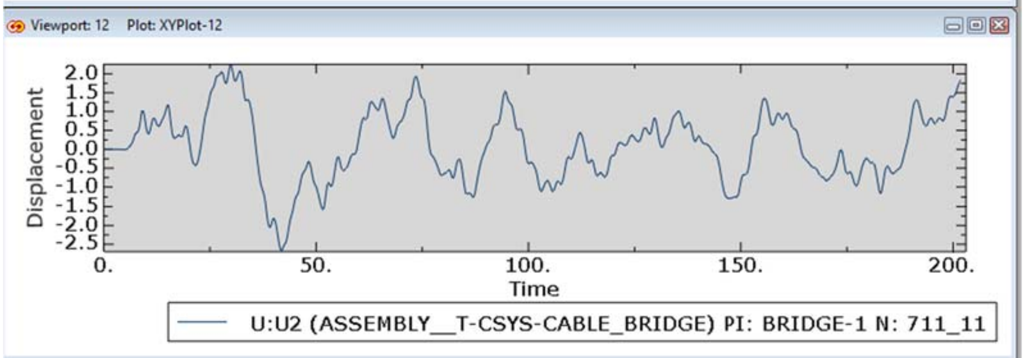

Viewport: 11 Plot: XYPlot-11
Displacement
3.0
2.0
1.0
0.0
-1.0
-2.0
0.
50.
100.
150.
200.
Time
U:U2 (ASSEMBLY__T-CSYS-CABLE_BRIDGE) PI: BRIDGE-1 N: 711_10

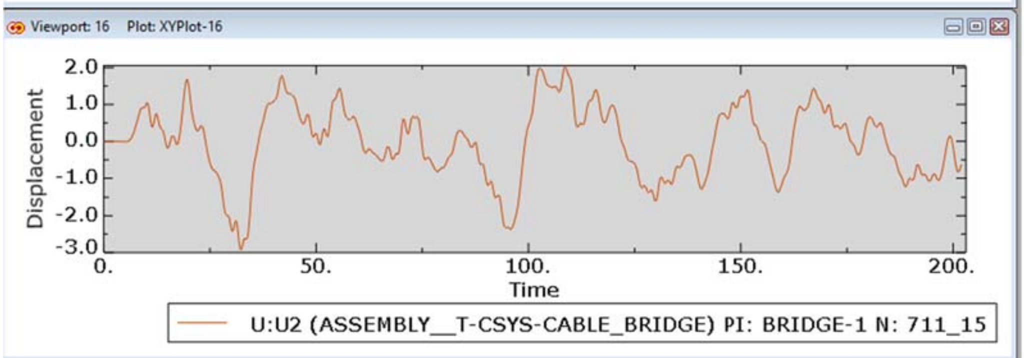

Viewport: 15 Plot: XYPlot-15
Displacement
2.0
1.0
0.0
-1.0
-2.0
0.
50.
100.
150.
200.
Time
U:U2 (ASSEMBLY__T-CSYS-CABLE_BRIDGE) PI: BRIDGE-1 N: 711_14

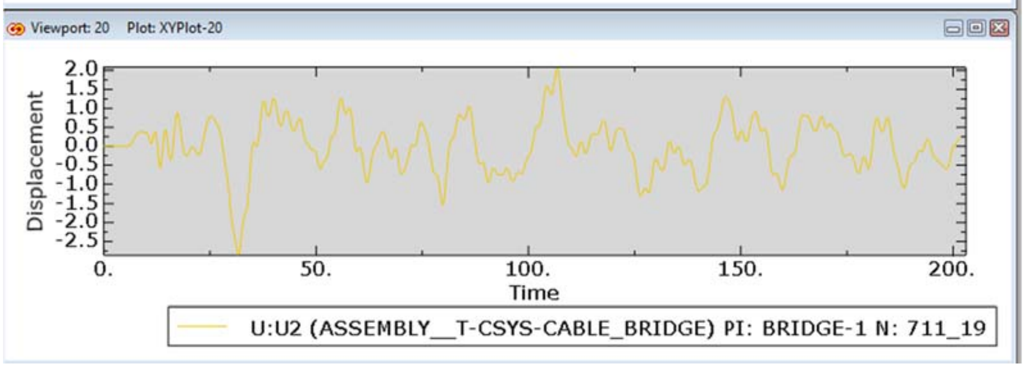

Viewport: 19 Plot: XYPlot-19
Displacement
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
0.
50.
100.
150.
200.
Time
U:U2 (ASSEMBLY__T-CSYS-CABLE_BRIDGE) PI: BRIDGE-1 N: 711_18


Viewport: 4 Plot: XYPlot-4
Displacement
Time
U:U2 (ASSEMBLY__T-CSYS-CABLE_BRIDGE) PI: BRIDGE-1 N: 711_3

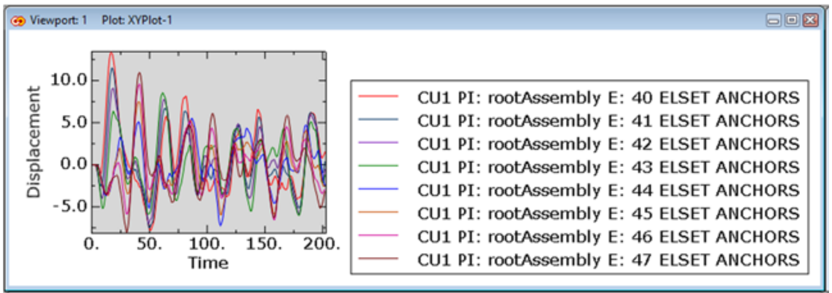

Viewport: 8 Plot: XYPlot-8
Displacement
Time
U:U2 (ASSEMBLY__T-CSYS-CABLE_BRIDGE) PI: BRIDGE-1 N: 711_7

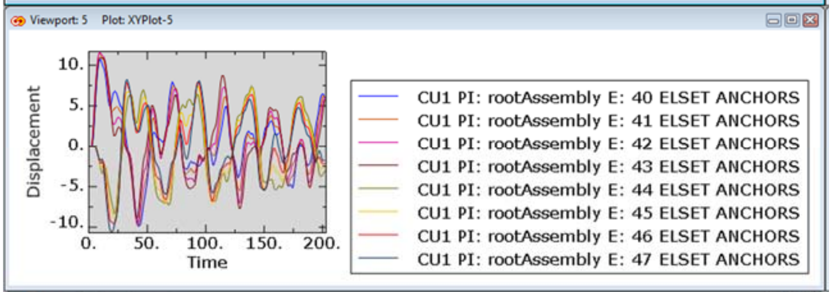

Viewport: 12 Plot: XYPlot-12
Displacement
Time
U:U2 (ASSEMBLY__T-CSYS-CABLE_BRIDGE) PI: BRIDGE-1 N: 711_11

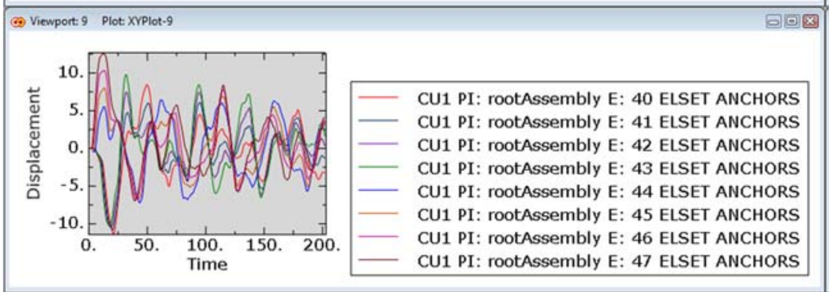

Viewport: 16 Plot: XYPlot-16
Displacement
Time
U:U2 (ASSEMBLY__T-CSYS-CABLE_BRIDGE) PI: BRIDGE-1 N: 711_15

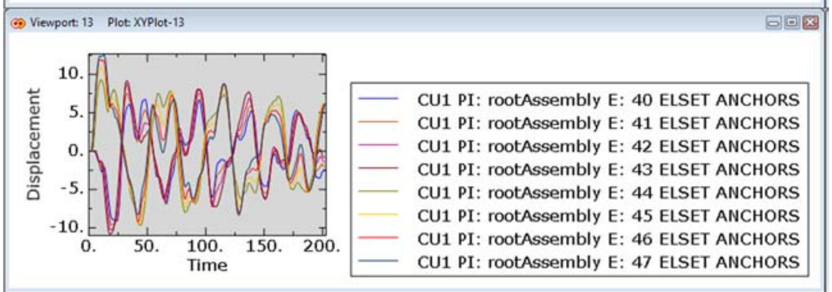

Viewport: 20 Plot: XYPlot-20
Displacement
Time
U:U2 (ASSEMBLY__T-CSYS-CABLE_BRIDGE) PI: BRIDGE-1 N: 711_19

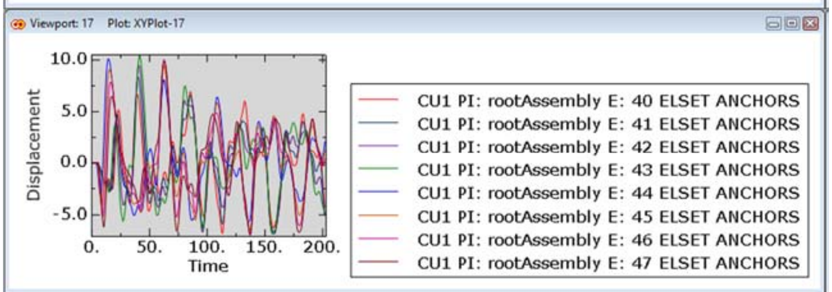
Transverse displacement of girder at landtower:

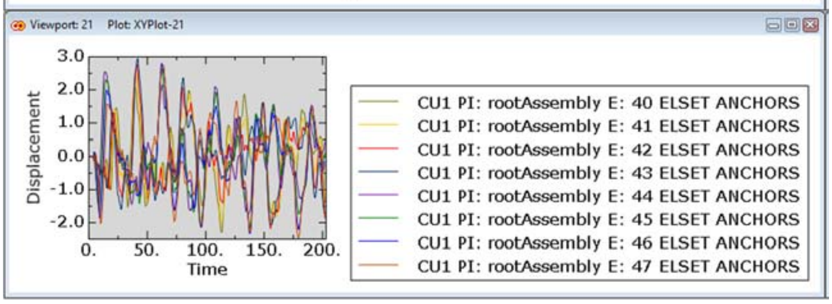


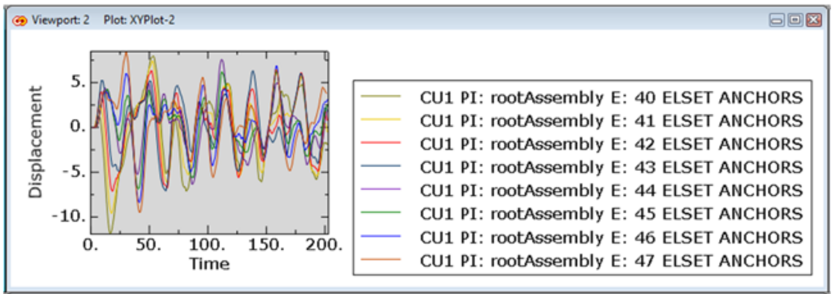


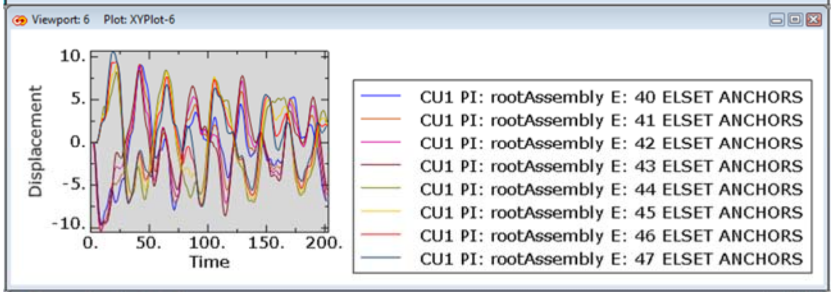


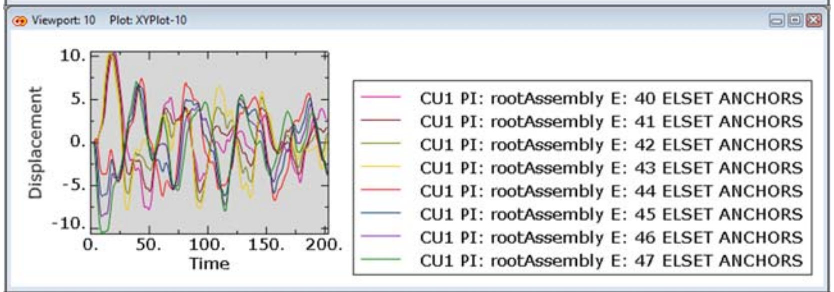


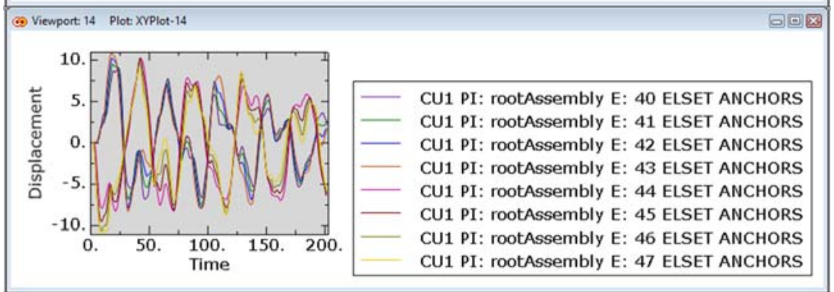


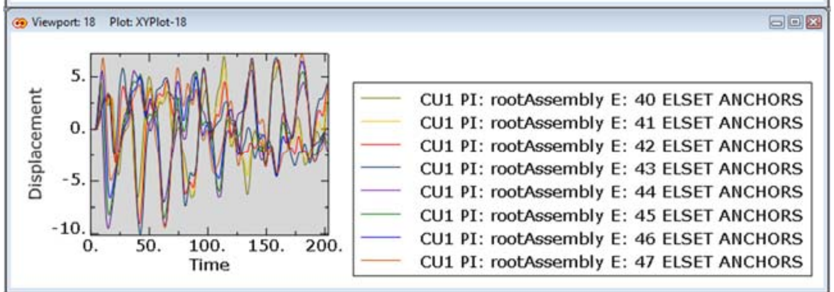


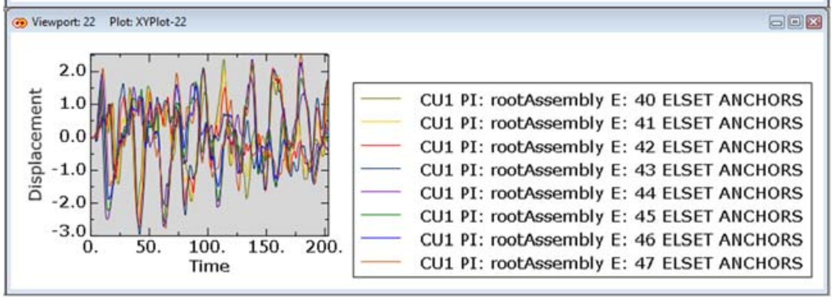

Viewport: 2 Plot: XYPlot-2
Displacement
5.
0.
-5.
-10.
0.
50.
100.
150.
200.
Time
CU1 PI: rootAssembly E: 40 ELSET ANCHORS
CU1 PI: rootAssembly E: 41 ELSET ANCHORS
CU1 PI: rootAssembly E: 42 ELSET ANCHORS
CU1 PI: rootAssembly E: 43 ELSET ANCHORS
CU1 PI: rootAssembly E: 44 ELSET ANCHORS
CU1 PI: rootAssembly E: 45 ELSET ANCHORS
CU1 PI: rootAssembly E: 46 ELSET ANCHORS
CU1 PI: rootAssembly E: 47 ELSET ANCHORS

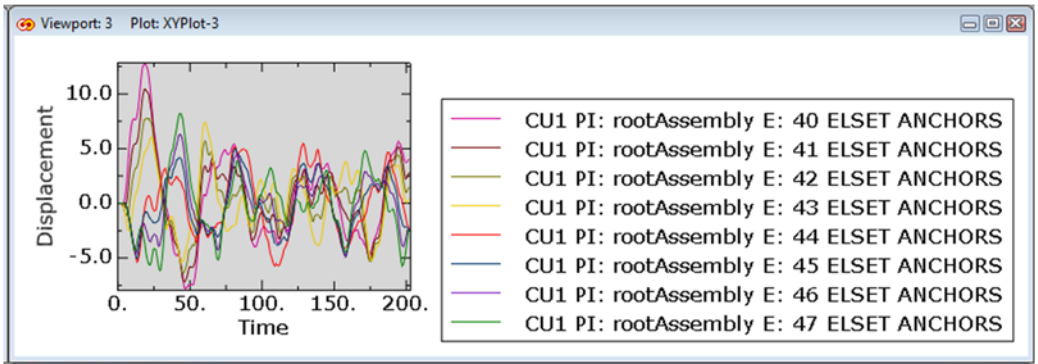

Viewport: 6 Plot: XYPlot-6
Displacement
10.
5.
0.
-5.
-10.
0.
50.
100.
150.
200.
Time
CU1 PI: rootAssembly E: 40 ELSET ANCHORS
CU1 PI: rootAssembly E: 41 ELSET ANCHORS
CU1 PI: rootAssembly E: 42 ELSET ANCHORS
CU1 PI: rootAssembly E: 43 ELSET ANCHORS
CU1 PI: rootAssembly E: 44 ELSET ANCHORS
CU1 PI: rootAssembly E: 45 ELSET ANCHORS
CU1 PI: rootAssembly E: 46 ELSET ANCHORS
CU1 PI: rootAssembly E: 47 ELSET ANCHORS

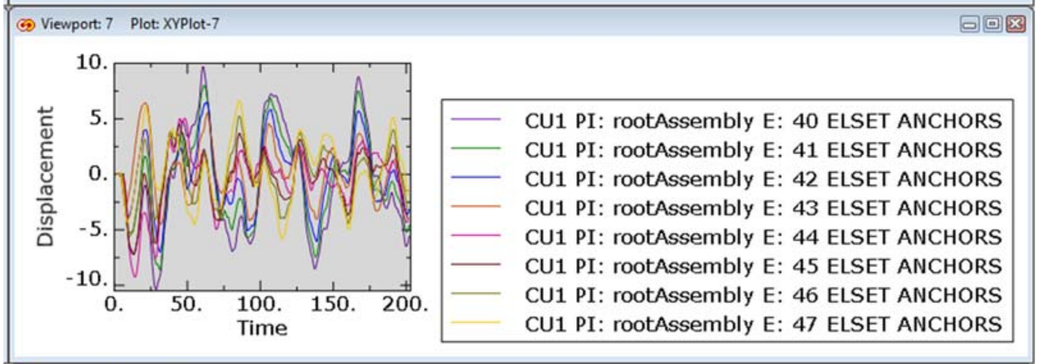

Viewport: 10 Plot: XYPlot-10
Displacement
10.
5.
0.
-5.
-10.
0.
50.
100.
150.
200.
Time
CU1 PI: rootAssembly E: 40 ELSET ANCHORS
CU1 PI: rootAssembly E: 41 ELSET ANCHORS
CU1 PI: rootAssembly E: 42 ELSET ANCHORS
CU1 PI: rootAssembly E: 43 ELSET ANCHORS
CU1 PI: rootAssembly E: 44 ELSET ANCHORS
CU1 PI: rootAssembly E: 45 ELSET ANCHORS
CU1 PI: rootAssembly E: 46 ELSET ANCHORS
CU1 PI: rootAssembly E: 47 ELSET ANCHORS

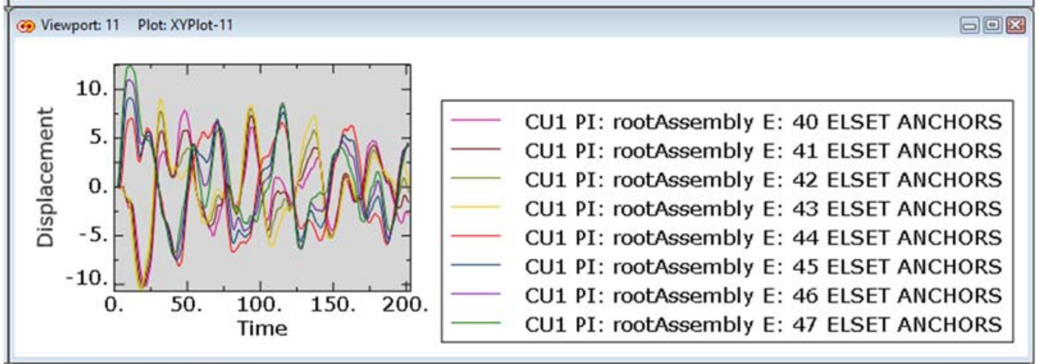

Viewport: 14 Plot: XYPlot-14
Displacement
10.
5.
0.
-5.
-10.
0.
50.
100.
150.
200.
Time
CU1 PI: rootAssembly E: 40 ELSET ANCHORS
CU1 PI: rootAssembly E: 41 ELSET ANCHORS
CU1 PI: rootAssembly E: 42 ELSET ANCHORS
CU1 PI: rootAssembly E: 43 ELSET ANCHORS
CU1 PI: rootAssembly E: 44 ELSET ANCHORS
CU1 PI: rootAssembly E: 45 ELSET ANCHORS
CU1 PI: rootAssembly E: 46 ELSET ANCHORS
CU1 PI: rootAssembly E: 47 ELSET ANCHORS

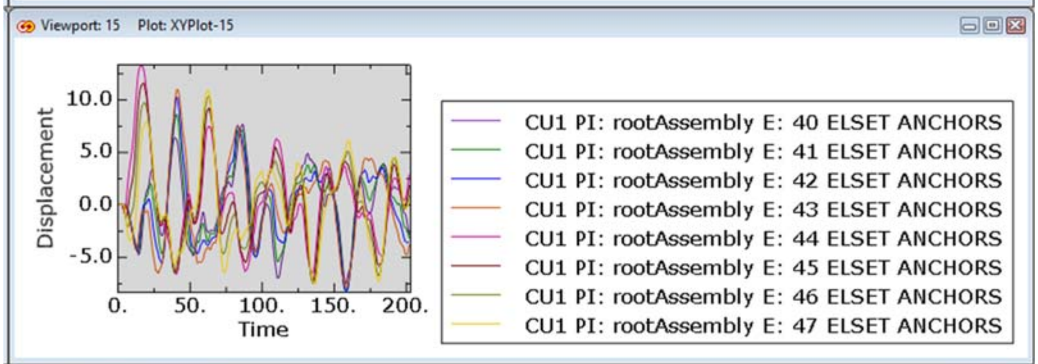

Viewport: 18 Plot: XYPlot-18
Displacement
5.
0.
-5.
-10.
0.
50.
100.
150.
200.
Time
CU1 PI: rootAssembly E: 40 ELSET ANCHORS
CU1 PI: rootAssembly E: 41 ELSET ANCHORS
CU1 PI: rootAssembly E: 42 ELSET ANCHORS
CU1 PI: rootAssembly E: 43 ELSET ANCHORS
CU1 PI: rootAssembly E: 44 ELSET ANCHORS
CU1 PI: rootAssembly E: 45 ELSET ANCHORS
CU1 PI: rootAssembly E: 46 ELSET ANCHORS
CU1 PI: rootAssembly E: 47 ELSET ANCHORS

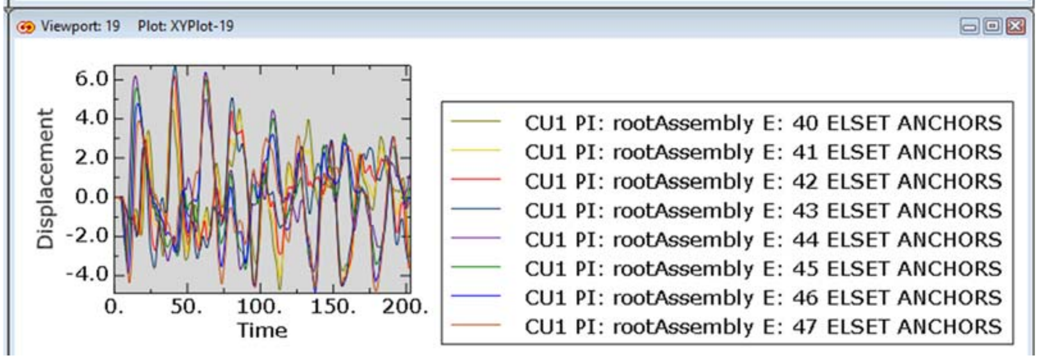

Viewport: 22 Plot: XYPlot-22
Displacement
2.0
1.0
0.0
-1.0
-2.0
-3.0
0.
50.
100.
150.
200.
Time
CU1 PI: rootAssembly E: 40 ELSET ANCHORS
CU1 PI: rootAssembly E: 41 ELSET ANCHORS
CU1 PI: rootAssembly E: 42 ELSET ANCHORS
CU1 PI: rootAssembly E: 43 ELSET ANCHORS
CU1 PI: rootAssembly E: 44 ELSET ANCHORS
CU1 PI: rootAssembly E: 45 ELSET ANCHORS
CU1 PI: rootAssembly E: 46 ELSET ANCHORS
CU1 PI: rootAssembly E: 47 ELSET ANCHORS

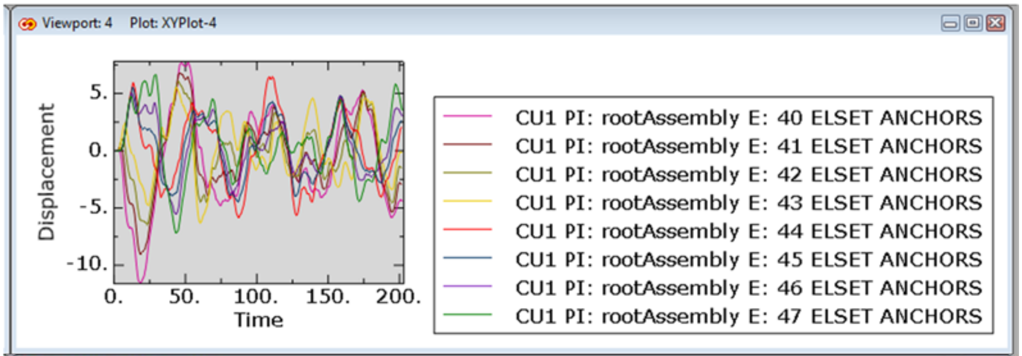

Viewport: 3 Plot: XYPlot-3
Displacement
10.0
5.0
0.0
-5.0
0. 50. 100. 150. 200.
Time
CU1 PI: rootAssembly E: 40 ELSET ANCHORS
CU1 PI: rootAssembly E: 41 ELSET ANCHORS
CU1 PI: rootAssembly E: 42 ELSET ANCHORS
CU1 PI: rootAssembly E: 43 ELSET ANCHORS
CU1 PI: rootAssembly E: 44 ELSET ANCHORS
CU1 PI: rootAssembly E: 45 ELSET ANCHORS
CU1 PI: rootAssembly E: 46 ELSET ANCHORS
CU1 PI: rootAssembly E: 47 ELSET ANCHORS

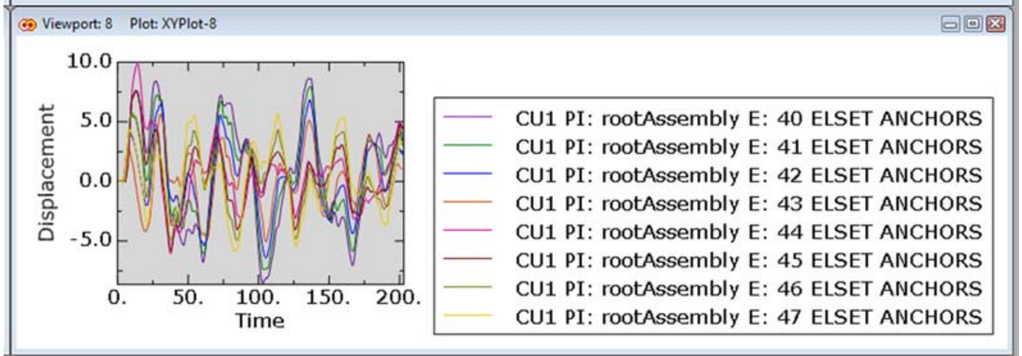

Viewport: 7 Plot: XYPlot-7
Displacement
10.
5.
0.
-5.
-10.
0. 50. 100. 150. 200.
Time
CU1 PI: rootAssembly E: 40 ELSET ANCHORS
CU1 PI: rootAssembly E: 41 ELSET ANCHORS
CU1 PI: rootAssembly E: 42 ELSET ANCHORS
CU1 PI: rootAssembly E: 43 ELSET ANCHORS
CU1 PI: rootAssembly E: 44 ELSET ANCHORS
CU1 PI: rootAssembly E: 45 ELSET ANCHORS
CU1 PI: rootAssembly E: 46 ELSET ANCHORS
CU1 PI: rootAssembly E: 47 ELSET ANCHORS

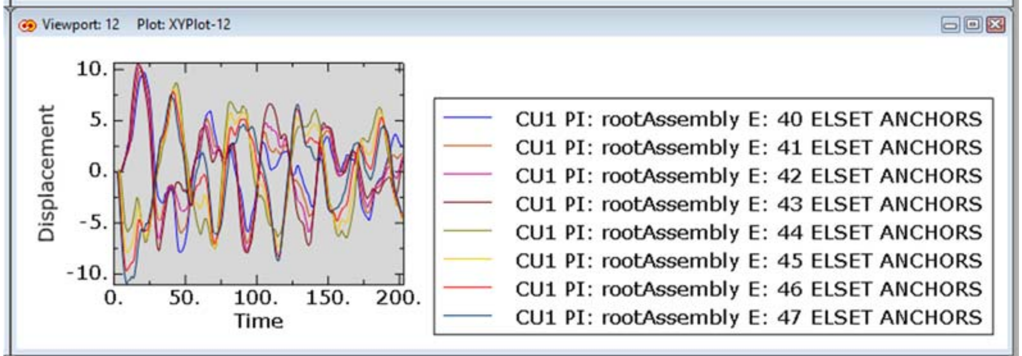

Viewport: 11 Plot: XYPlot-11
Displacement
10.
5.
0.
-5.
-10.
0. 50. 100. 150. 200.
Time
CU1 PI: rootAssembly E: 40 ELSET ANCHORS
CU1 PI: rootAssembly E: 41 ELSET ANCHORS
CU1 PI: rootAssembly E: 42 ELSET ANCHORS
CU1 PI: rootAssembly E: 43 ELSET ANCHORS
CU1 PI: rootAssembly E: 44 ELSET ANCHORS
CU1 PI: rootAssembly E: 45 ELSET ANCHORS
CU1 PI: rootAssembly E: 46 ELSET ANCHORS
CU1 PI: rootAssembly E: 47 ELSET ANCHORS

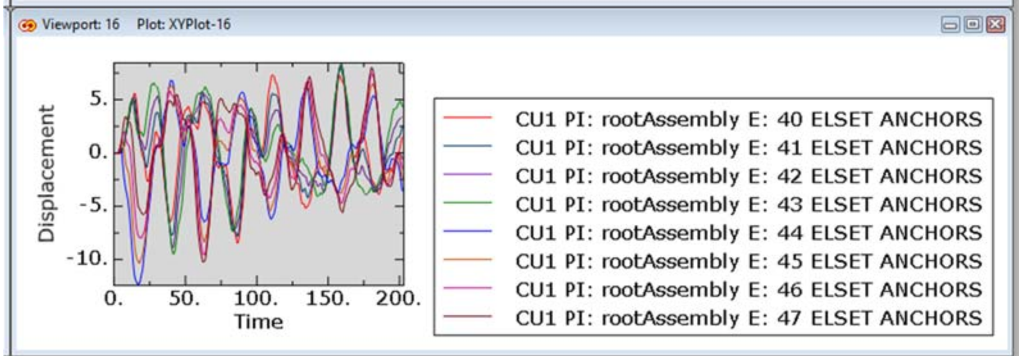

Viewport: 15 Plot: XYPlot-15
Displacement
10.0
5.0
0.0
-5.0
0. 50. 100. 150. 200.
Time
CU1 PI: rootAssembly E: 40 ELSET ANCHORS
CU1 PI: rootAssembly E: 41 ELSET ANCHORS
CU1 PI: rootAssembly E: 42 ELSET ANCHORS
CU1 PI: rootAssembly E: 43 ELSET ANCHORS
CU1 PI: rootAssembly E: 44 ELSET ANCHORS
CU1 PI: rootAssembly E: 45 ELSET ANCHORS
CU1 PI: rootAssembly E: 46 ELSET ANCHORS
CU1 PI: rootAssembly E: 47 ELSET ANCHORS

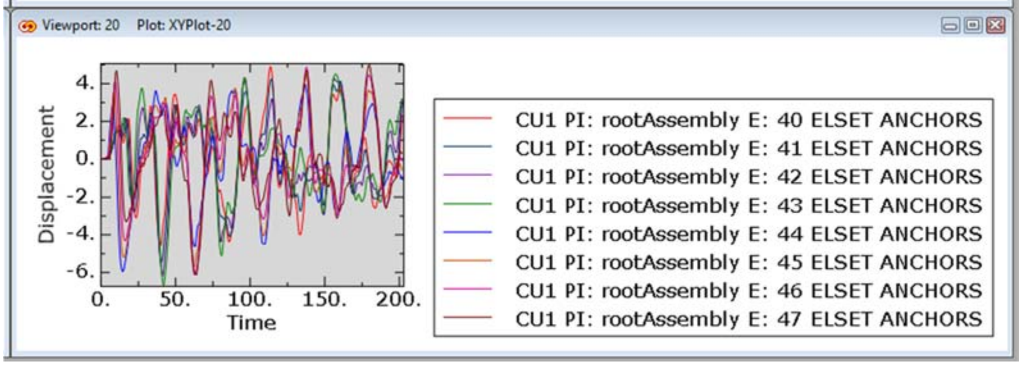

Viewport: 19 Plot: XYPlot-19
Displacement
6.0
4.0
2.0
0.0
-2.0
-4.0
0. 50. 100. 150. 200.
Time
CU1 PI: rootAssembly E: 40 ELSET ANCHORS
CU1 PI: rootAssembly E: 41 ELSET ANCHORS
CU1 PI: rootAssembly E: 42 ELSET ANCHORS
CU1 PI: rootAssembly E: 43 ELSET ANCHORS
CU1 PI: rootAssembly E: 44 ELSET ANCHORS
CU1 PI: rootAssembly E: 45 ELSET ANCHORS
CU1 PI: rootAssembly E: 46 ELSET ANCHORS
CU1 PI: rootAssembly E: 47 ELSET ANCHORS


Viewport: 4 Plot: XYPlot-4
Displacement
5.
0.
-5.
-10.
0.
50.
100.
150.
200.
Time
CU1 PI: rootAssembly E: 40 ELSET ANCHORS
CU1 PI: rootAssembly E: 41 ELSET ANCHORS
CU1 PI: rootAssembly E: 42 ELSET ANCHORS
CU1 PI: rootAssembly E: 43 ELSET ANCHORS
CU1 PI: rootAssembly E: 44 ELSET ANCHORS
CU1 PI: rootAssembly E: 45 ELSET ANCHORS
CU1 PI: rootAssembly E: 46 ELSET ANCHORS
CU1 PI: rootAssembly E: 47 ELSET ANCHORS


Viewport: 8 Plot: XYPlot-8
Displacement
10.0
5.0
0.0
-5.0
0.
50.
100.
150.
200.
Time
CU1 PI: rootAssembly E: 40 ELSET ANCHORS
CU1 PI: rootAssembly E: 41 ELSET ANCHORS
CU1 PI: rootAssembly E: 42 ELSET ANCHORS
CU1 PI: rootAssembly E: 43 ELSET ANCHORS
CU1 PI: rootAssembly E: 44 ELSET ANCHORS
CU1 PI: rootAssembly E: 45 ELSET ANCHORS
CU1 PI: rootAssembly E: 46 ELSET ANCHORS
CU1 PI: rootAssembly E: 47 ELSET ANCHORS


Viewport: 12 Plot: XYPlot-12
Displacement
10.
5.
0.
-5.
-10.
0.
50.
100.
150.
200.
Time
CU1 PI: rootAssembly E: 40 ELSET ANCHORS
CU1 PI: rootAssembly E: 41 ELSET ANCHORS
CU1 PI: rootAssembly E: 42 ELSET ANCHORS
CU1 PI: rootAssembly E: 43 ELSET ANCHORS
CU1 PI: rootAssembly E: 44 ELSET ANCHORS
CU1 PI: rootAssembly E: 45 ELSET ANCHORS
CU1 PI: rootAssembly E: 46 ELSET ANCHORS
CU1 PI: rootAssembly E: 47 ELSET ANCHORS

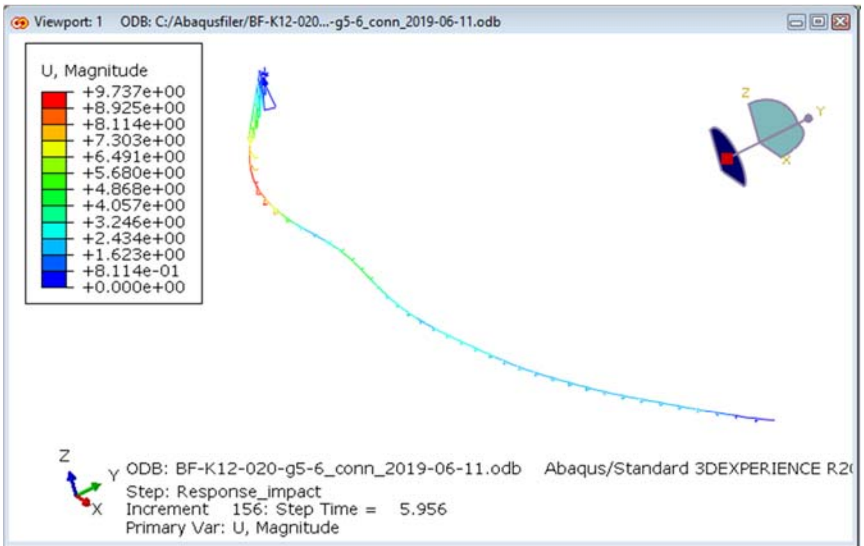

Viewport: 16 Plot: XYPlot-16
Displacement
5.
0.
-5.
-10.
0.
50.
100.
150.
200.
Time
CU1 PI: rootAssembly E: 40 ELSET ANCHORS
CU1 PI: rootAssembly E: 41 ELSET ANCHORS
CU1 PI: rootAssembly E: 42 ELSET ANCHORS
CU1 PI: rootAssembly E: 43 ELSET ANCHORS
CU1 PI: rootAssembly E: 44 ELSET ANCHORS
CU1 PI: rootAssembly E: 45 ELSET ANCHORS
CU1 PI: rootAssembly E: 46 ELSET ANCHORS
CU1 PI: rootAssembly E: 47 ELSET ANCHORS

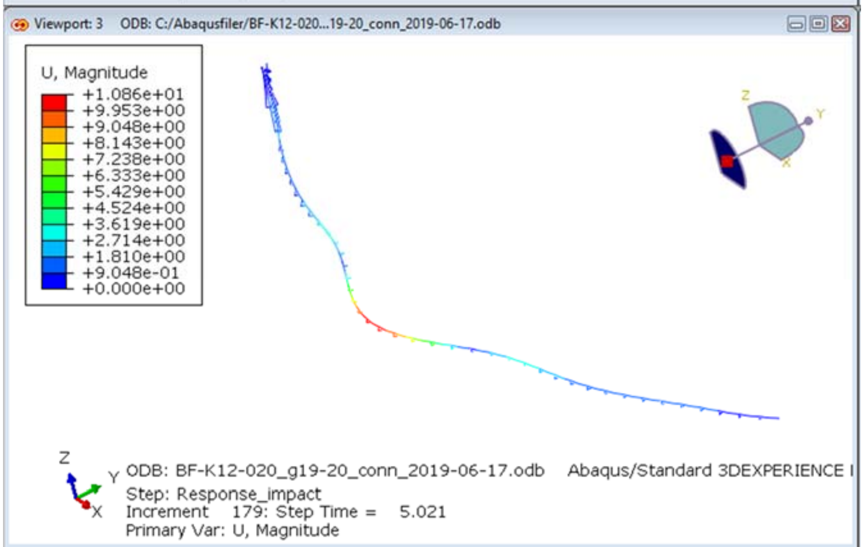

Viewport: 20 Plot: XYPlot-20
Displacement
4.
2.
0.
-2.
-4.
-6.
0.
50.
100.
150.
200.
Time
CU1 PI: rootAssembly E: 40 ELSET ANCHORS
CU1 PI: rootAssembly E: 41 ELSET ANCHORS
CU1 PI: rootAssembly E: 42 ELSET ANCHORS
CU1 PI: rootAssembly E: 43 ELSET ANCHORS
CU1 PI: rootAssembly E: 44 ELSET ANCHORS
CU1 PI: rootAssembly E: 45 ELSET ANCHORS
CU1 PI: rootAssembly E: 46 ELSET ANCHORS
CU1 PI: rootAssembly E: 47 ELSET ANCHORS

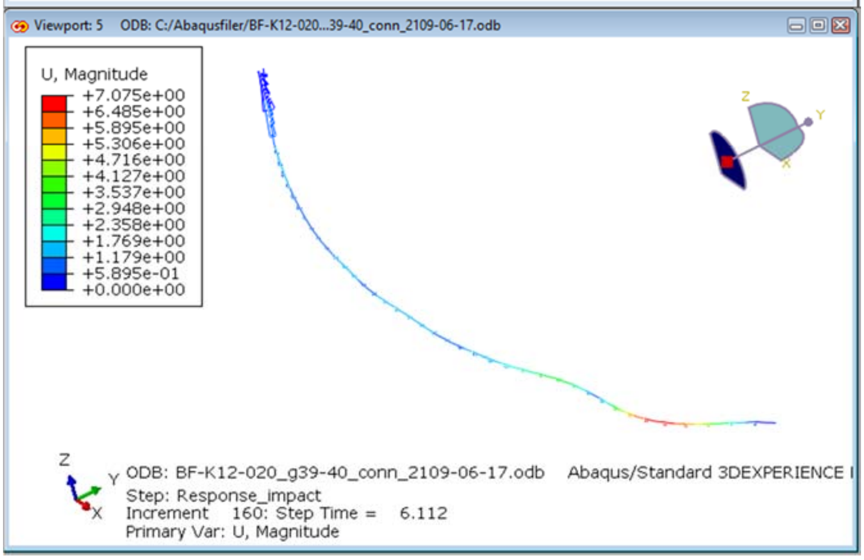
C.3 Ship-girder connector analysis

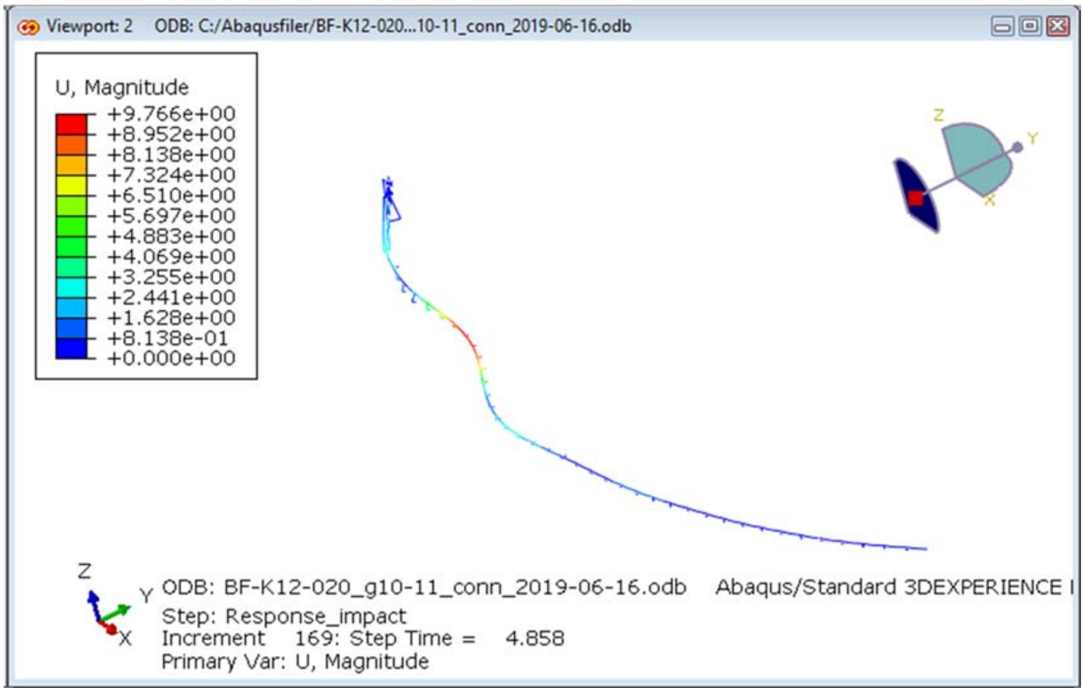
Extended results from the spring-mass-system analysis with connectors.

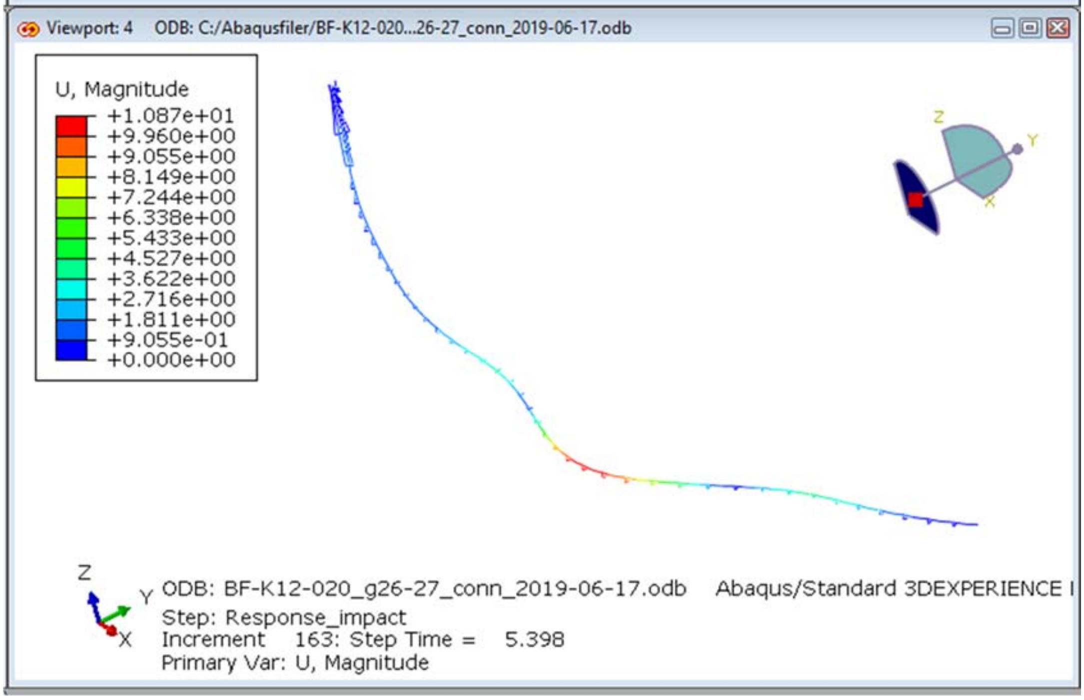
Displacement of bridge a few seconds into the impact – to show the direction of the impact:



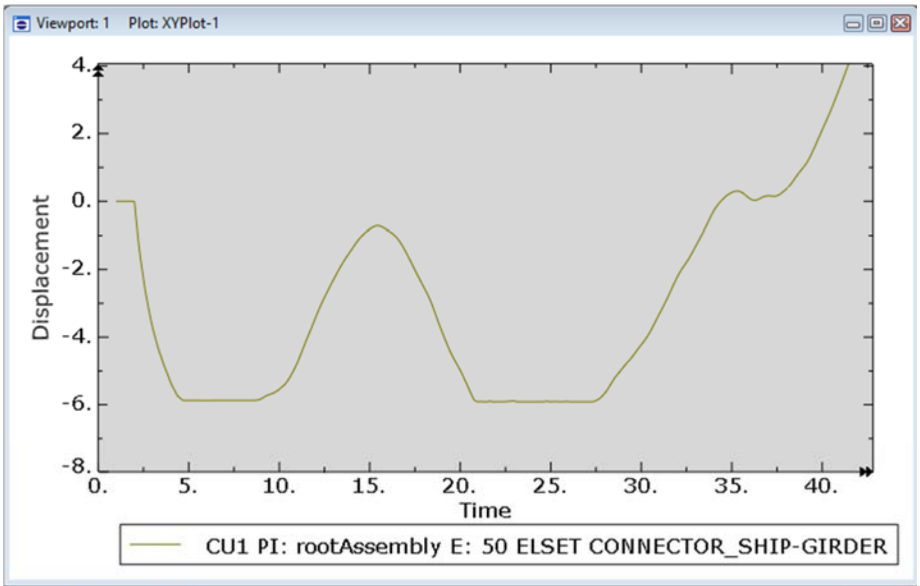


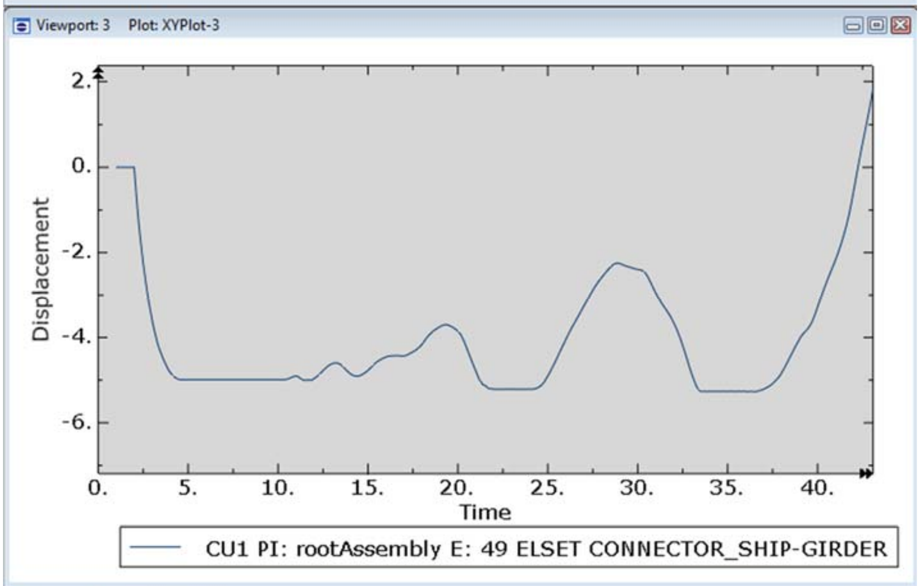


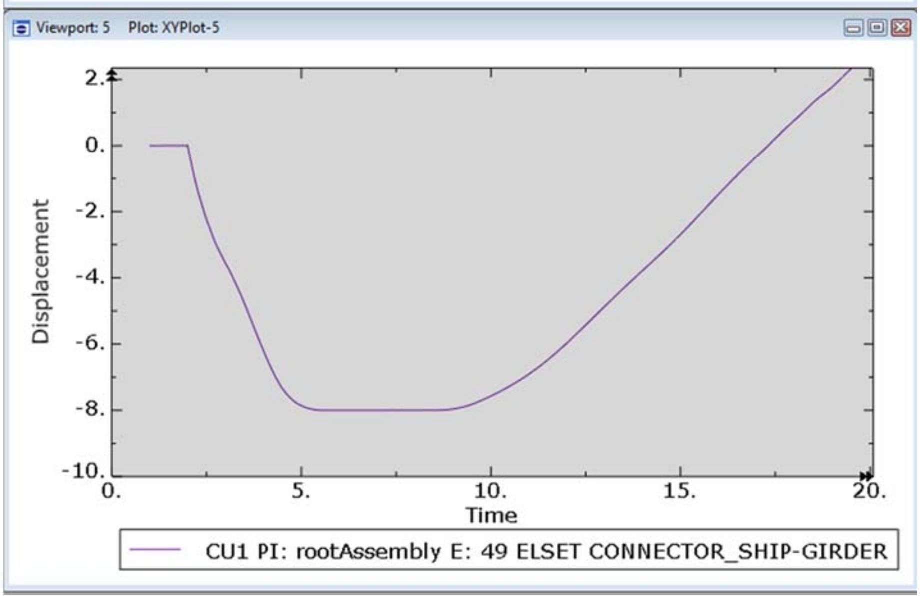

Viewport: 2 ODB: C:/Abaqusfiler/BF-K12-020...10-11_conn_2019-06-16.odb
U, Magnitude
+9.766e+00
+8.952e+00
+8.138e+00
+7.324e+00
+6.510e+00
+5.697e+00
+4.883e+00
+4.069e+00
+3.255e+00
+2.441e+00
+1.628e+00
+8.138e-01
+0.000e+00
ODB: BF-K12-020_g10-11_conn_2019-06-16.odb Abaqus/Standard 3DEXPERIENCE
Step: Response_impact
Increment 169: Step Time = 4.858
Primary Var: U, Magnitude

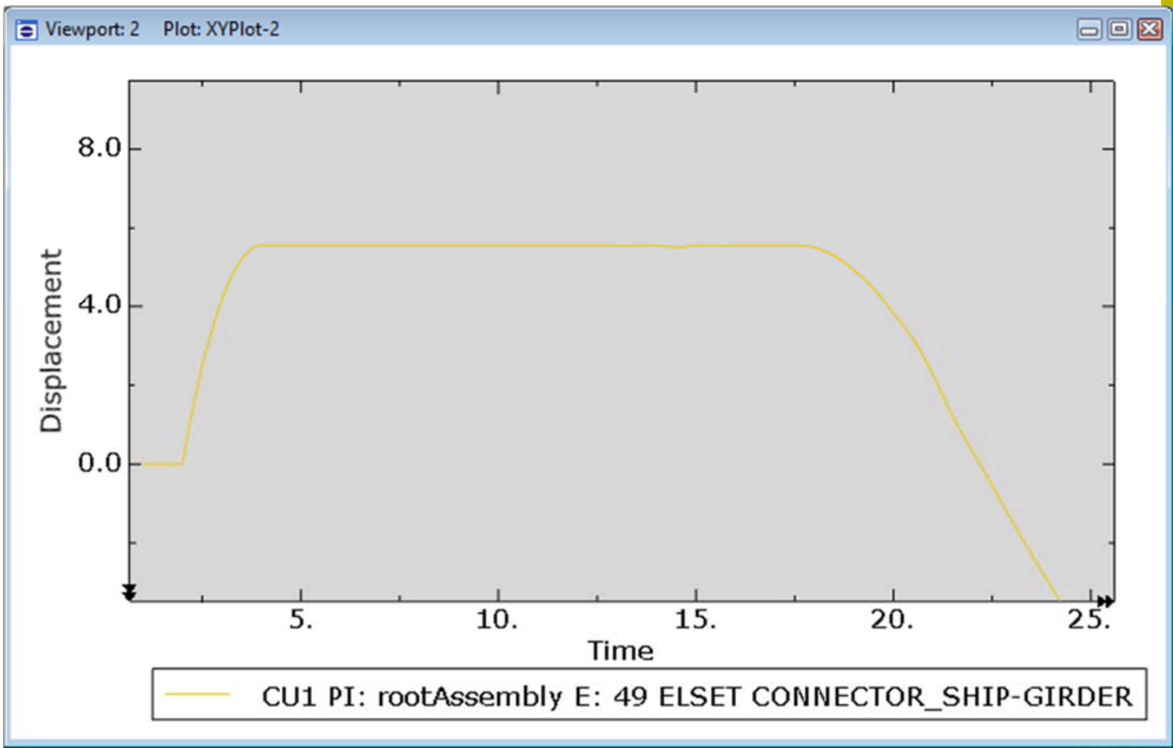

Viewport: 4 ODB: C:/Abaqusfiler/BF-K12-020...26-27_conn_2019-06-17.odb
U, Magnitude
+1.087e+01
+9.960e+00
+9.055e+00
+8.149e+00
+7.244e+00
+6.338e+00
+5.433e+00
+4.527e+00
+3.622e+00
+2.716e+00
+1.811e+00
+9.055e-01
+0.000e+00
ODB: BF-K12-020_g26-27_conn_2019-06-17.odb Abaqus/Standard 3DEXPERIENCE
Step: Response_impact
Increment 163: Step Time = 5.398
Primary Var: U, Magnitude

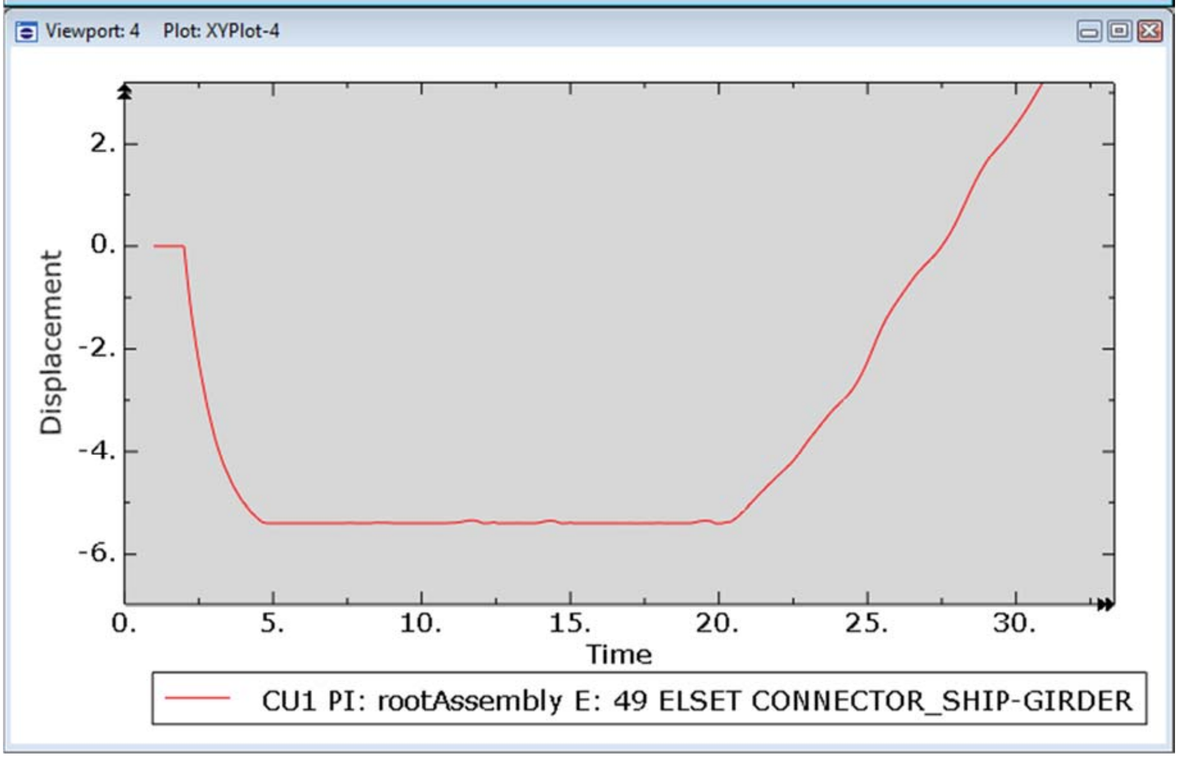
Force-indentation in connector between ship and girder [m]:








Viewport: 2 Plot: XYPlot-2
8.0
4.0
0.0
Displacement
5.
10.
15.
20.
25.
Time
CU1 PI: rootAssembly E: 49 ELSET CONNECTOR_SHIP-GIRDER

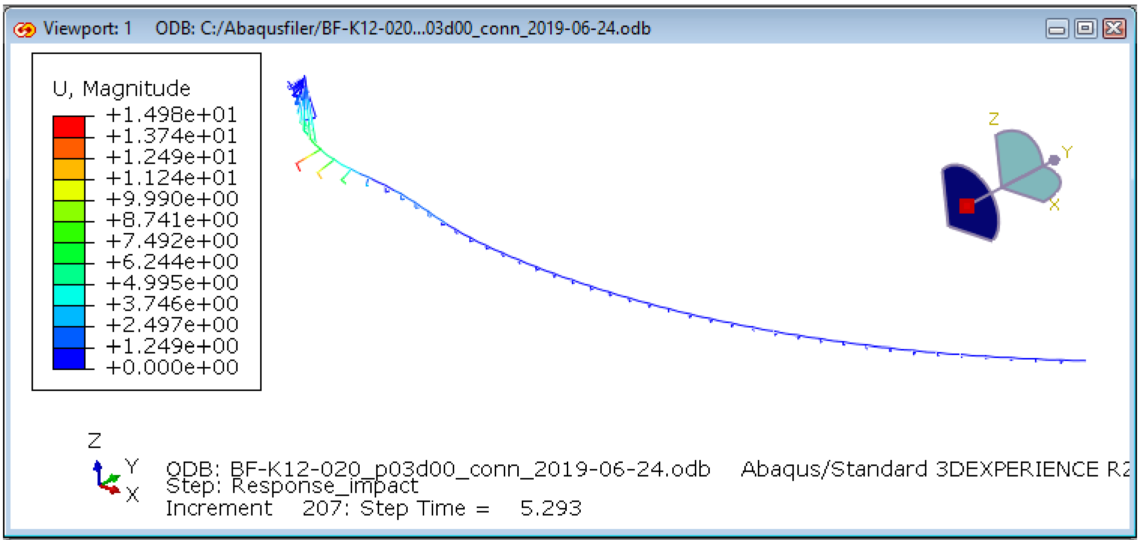

Viewport: 4 Plot: XYPlot-4
2.
0.
-2.
-4.
-6.
Displacement
0.
5.
10.
15.
20.
25.
30.
Time
CU1 PI: rootAssembly E: 49 ELSET CONNECTOR_SHIP-GIRDER

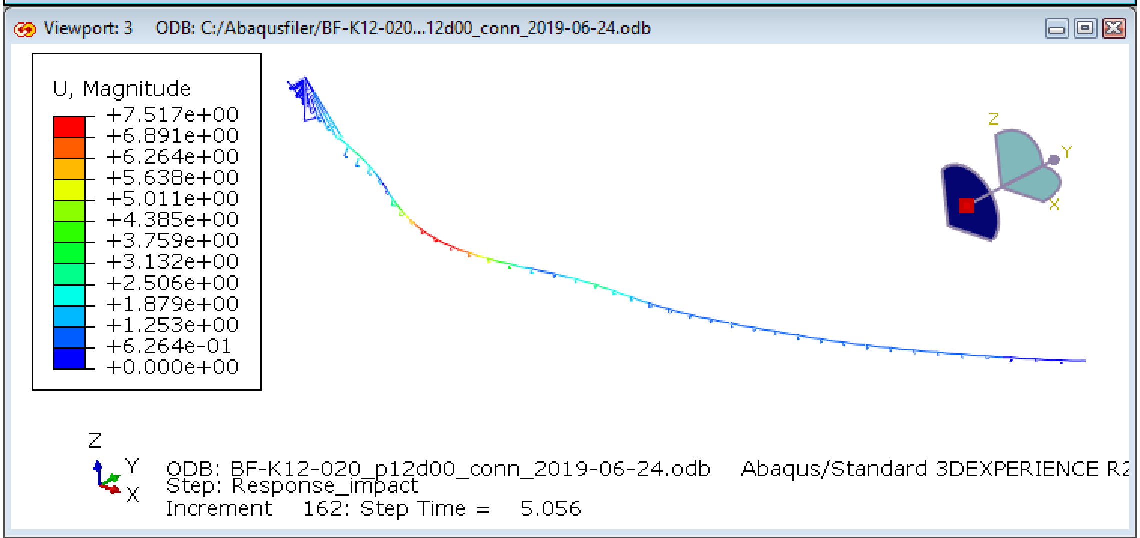
C.4 Ship-pontoon analysis

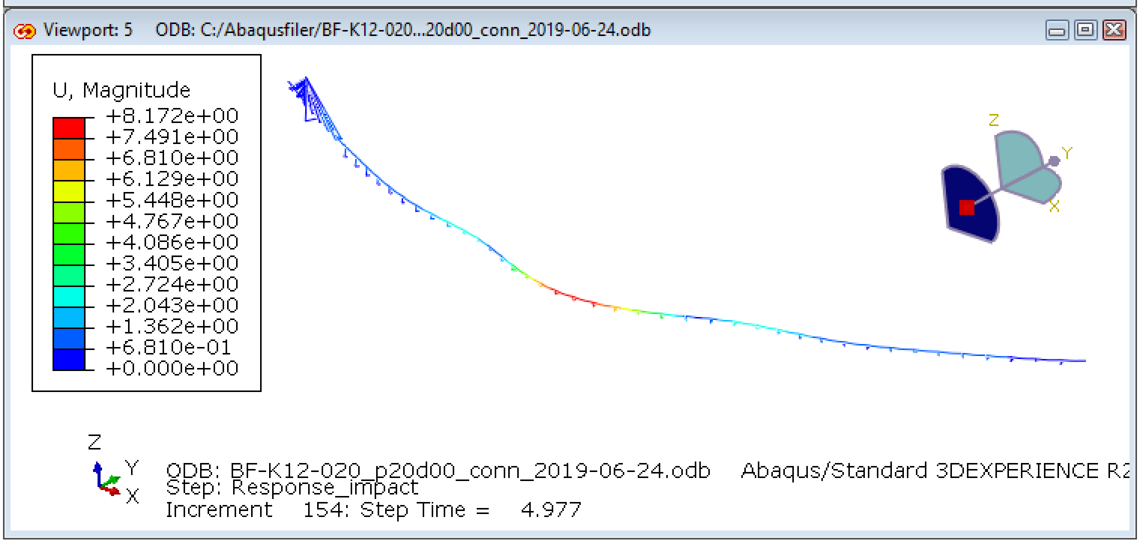
C.4.1 Head-on impacts (0 deg) – container ship

Extended results are shown for the head on impacts on the pontoons in axis 3, 12 and 20. All figures show the same result from the different axis – pontoon 3 impact on top, pontoon 12 impact in the middle and pontoon 20 on the bottom. The force-indentation curve is shown in section 3.2.1.

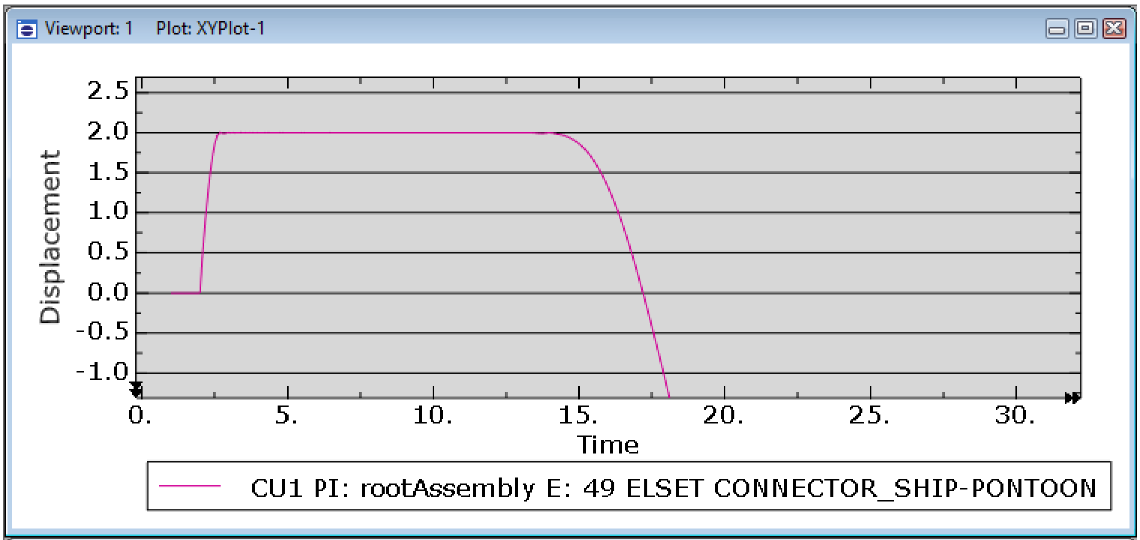
Deformation in m, scale factor 15:

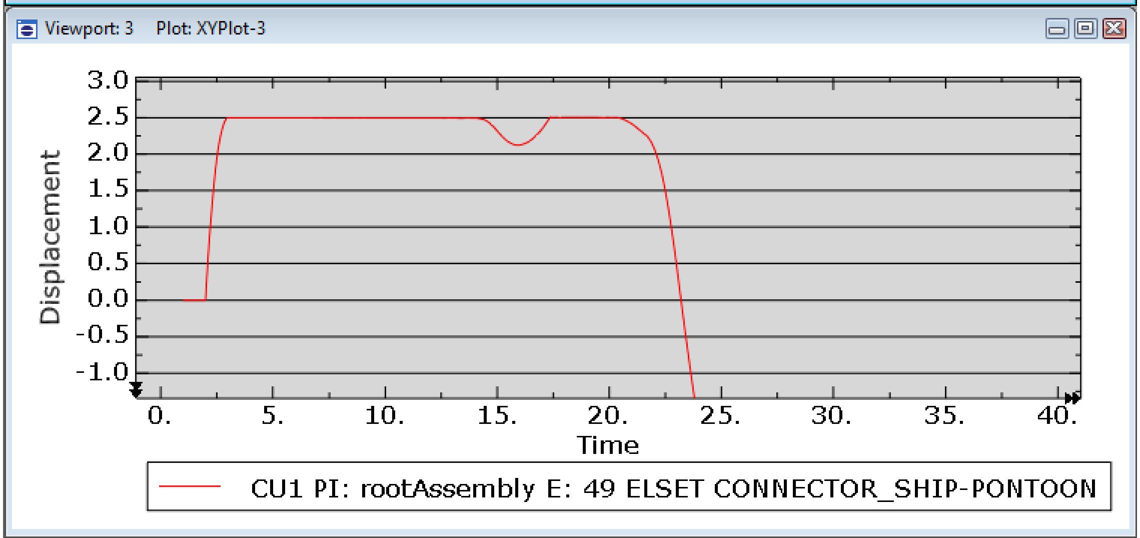


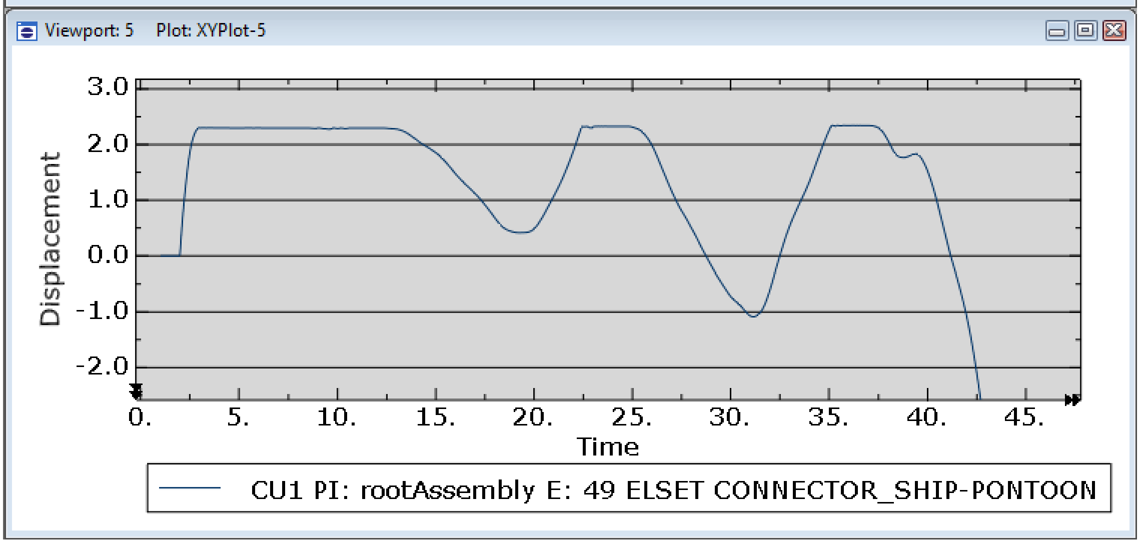




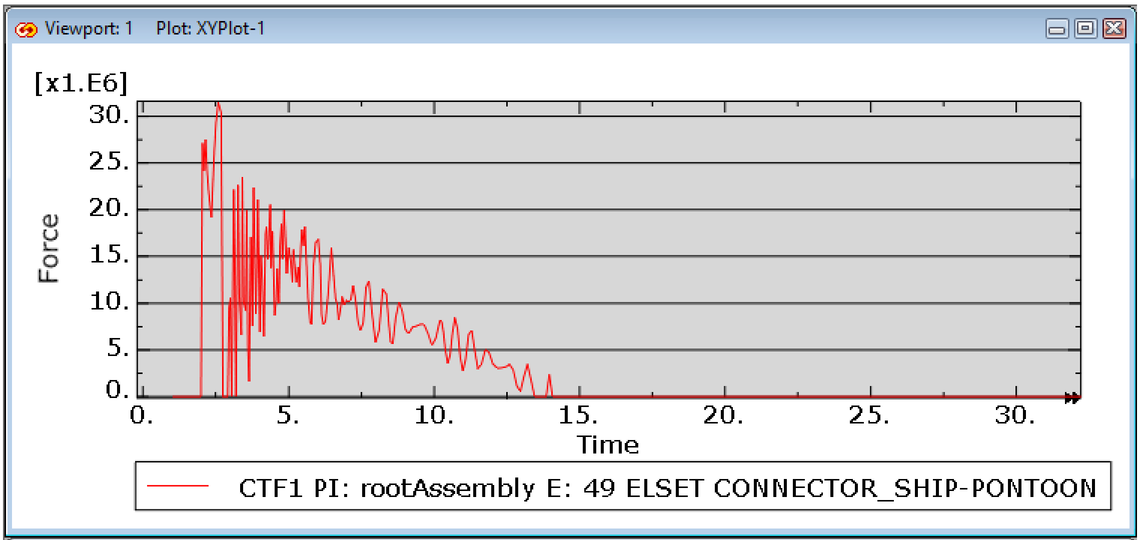
Indentation [m] between ship and pontoon:

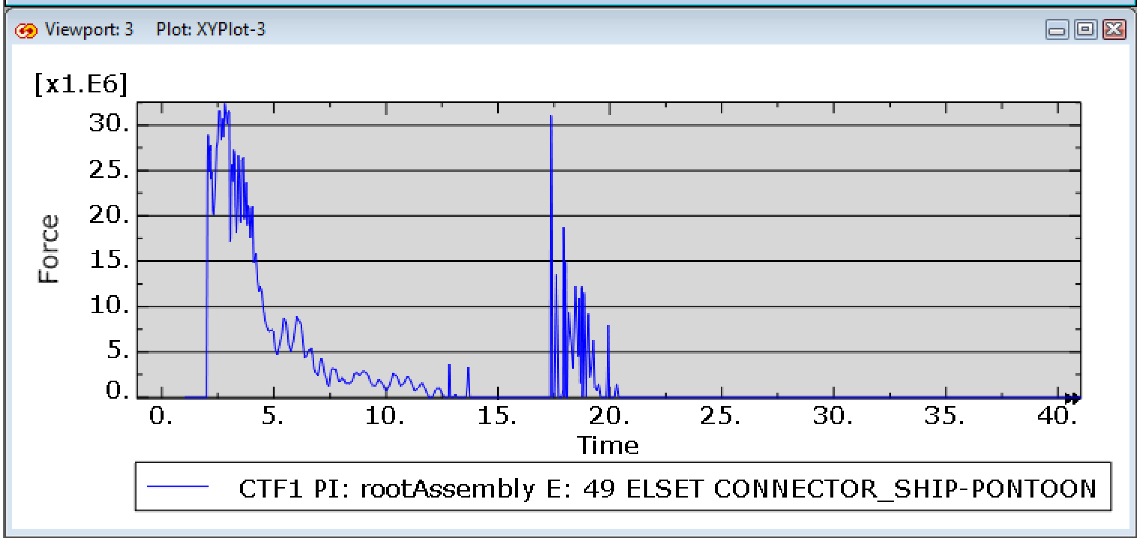


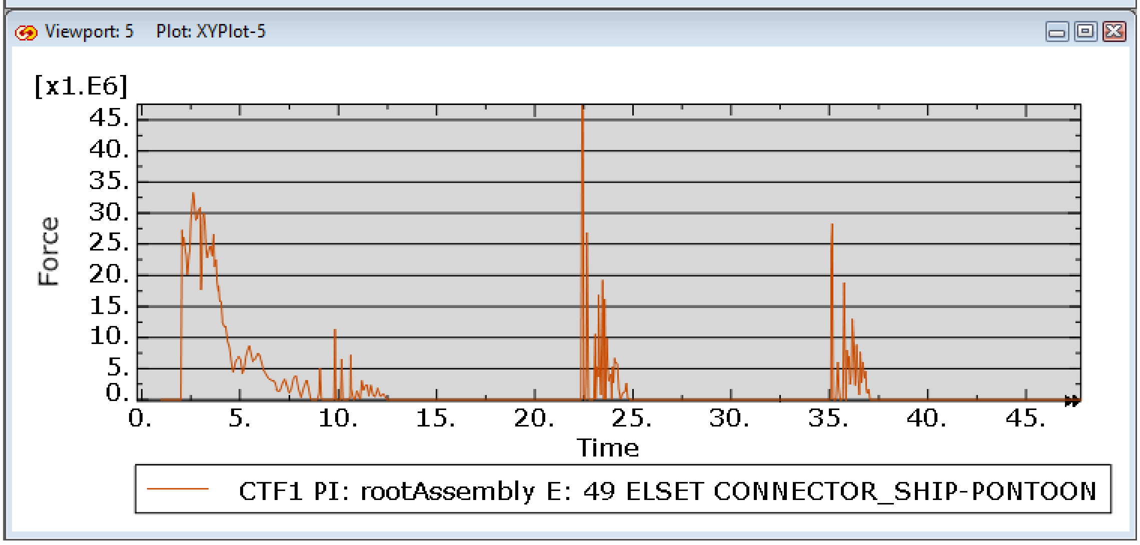




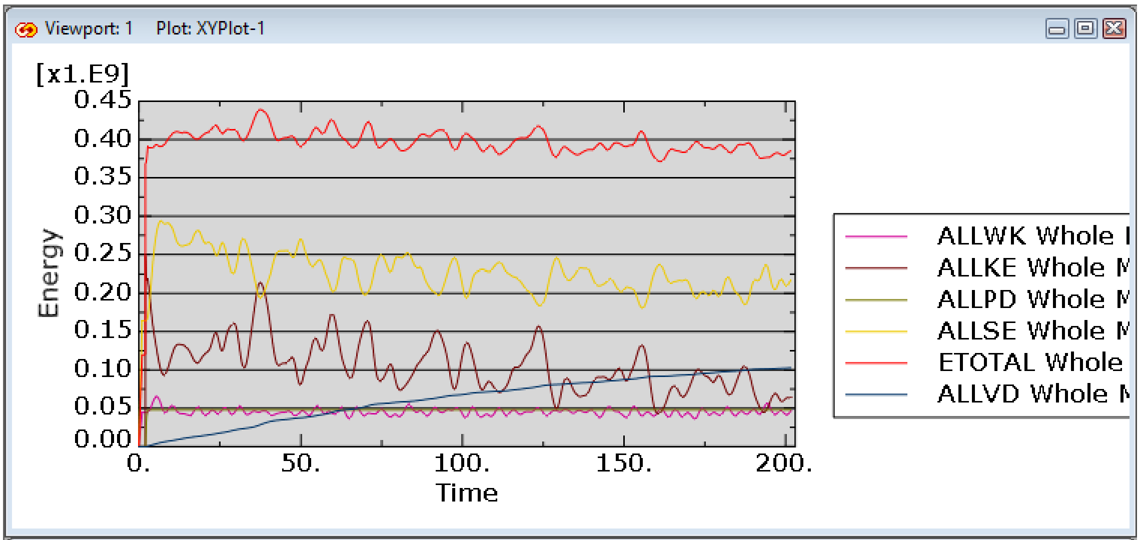
Force [N] between ship and pontoon:

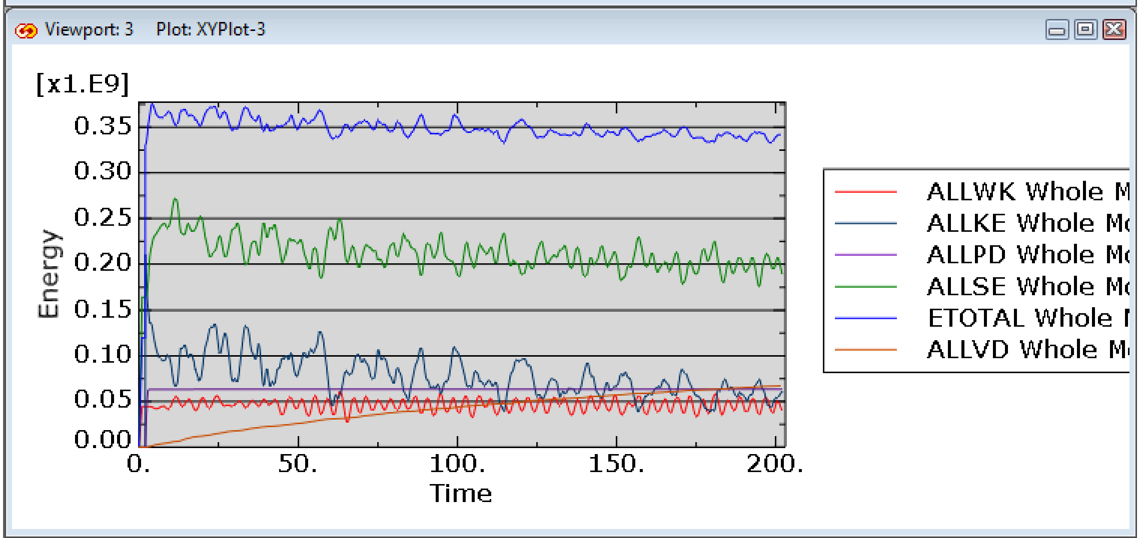


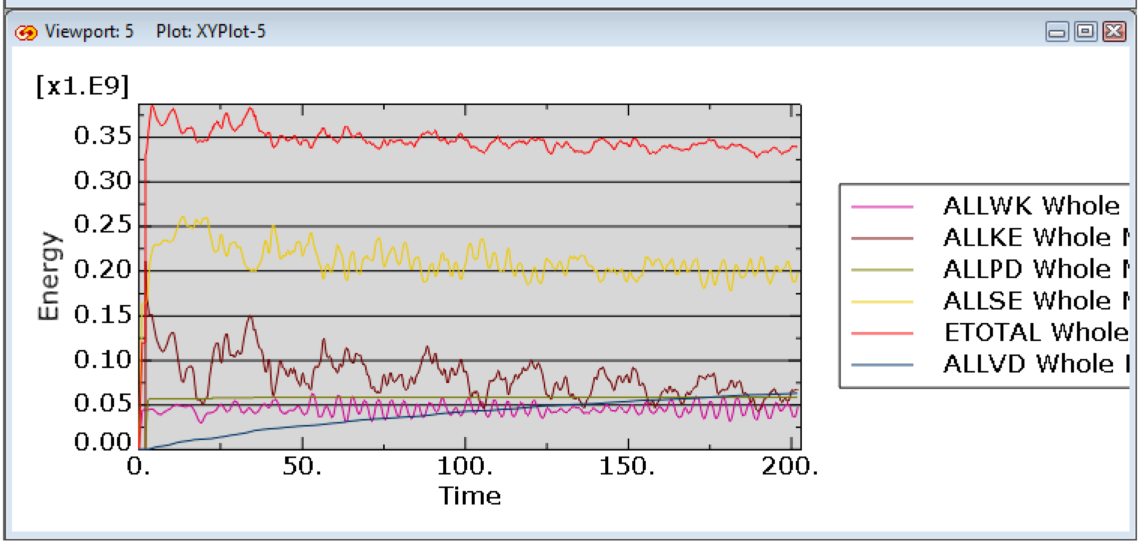




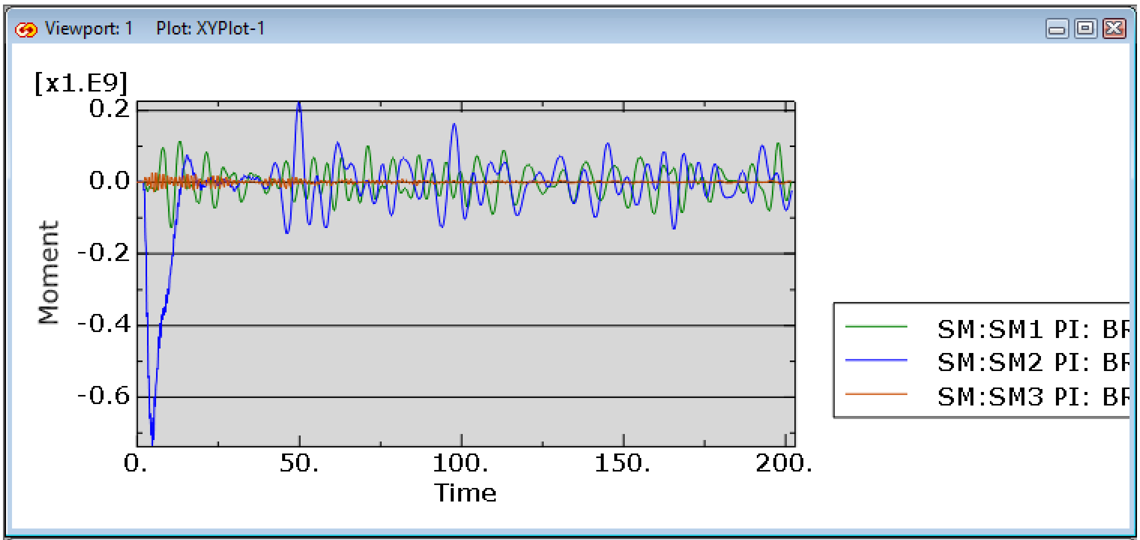
Selected energy plots from analysis [J] (see Appendix A for description of energies):

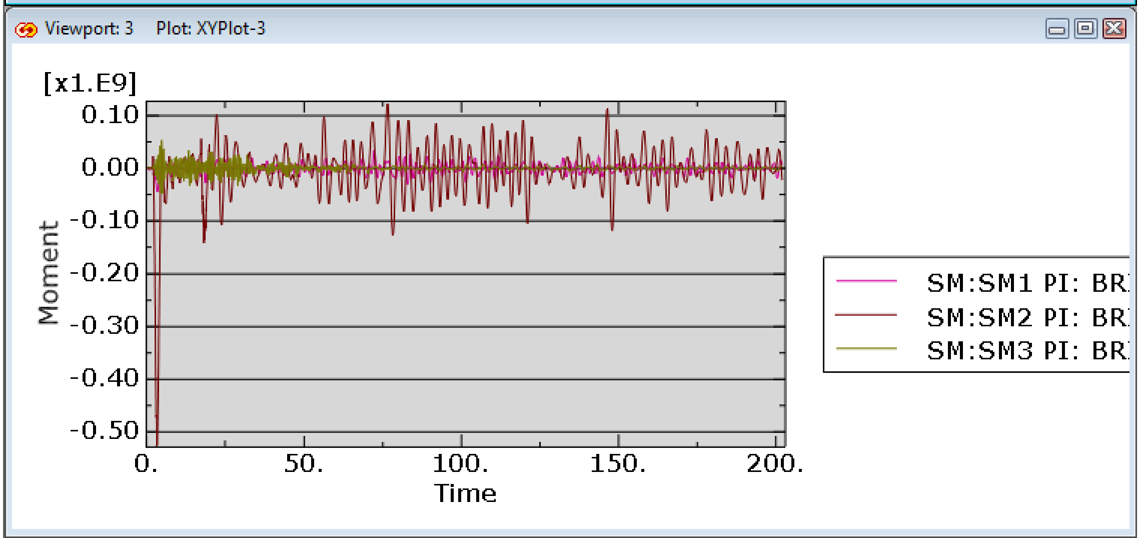


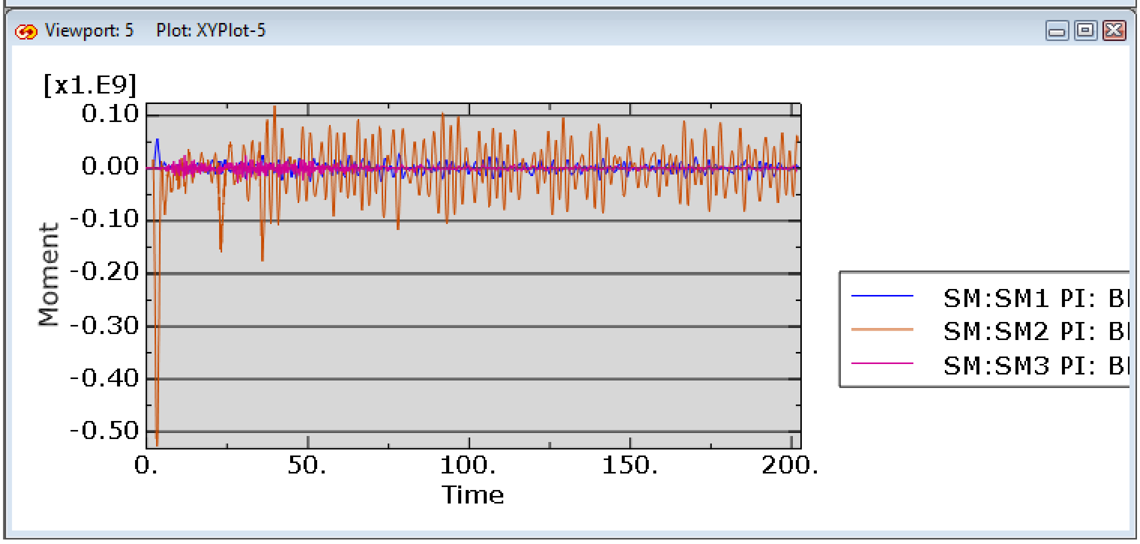




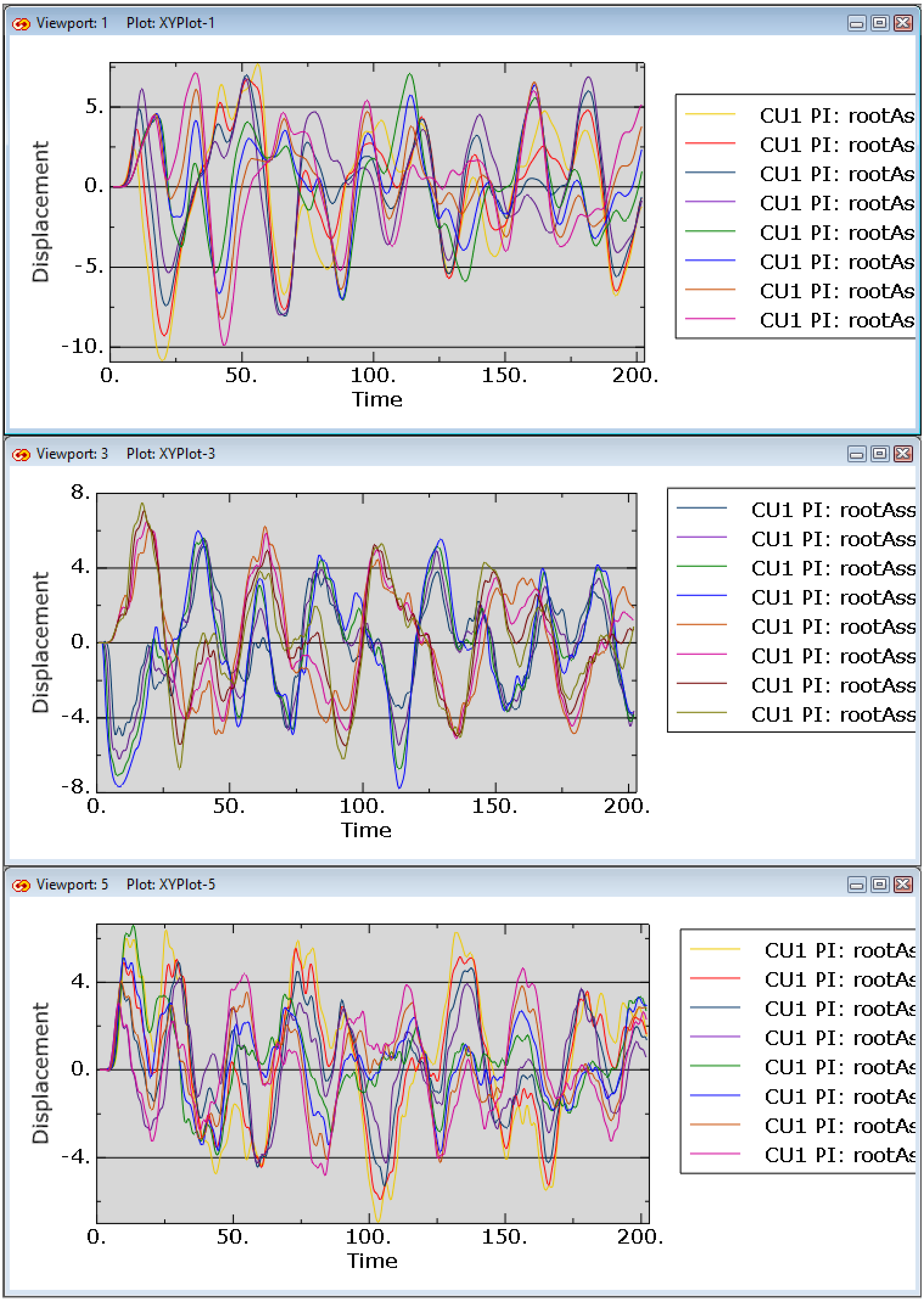
Moments in column top [Nm] (SM1 -weak axis, SM2 – strong axis, SM3 – torsion):







Elongations of anchors [m]:

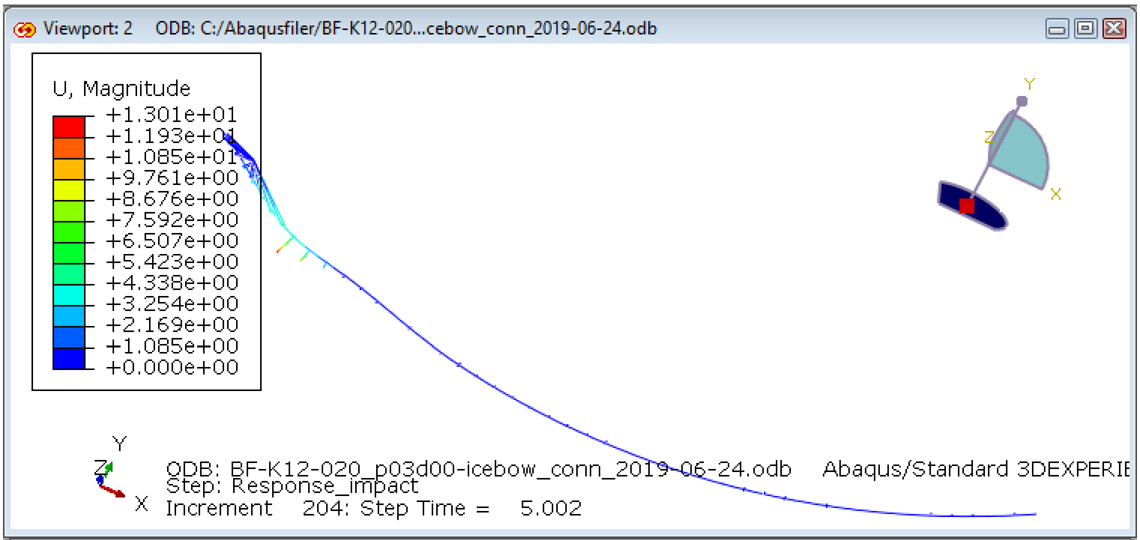


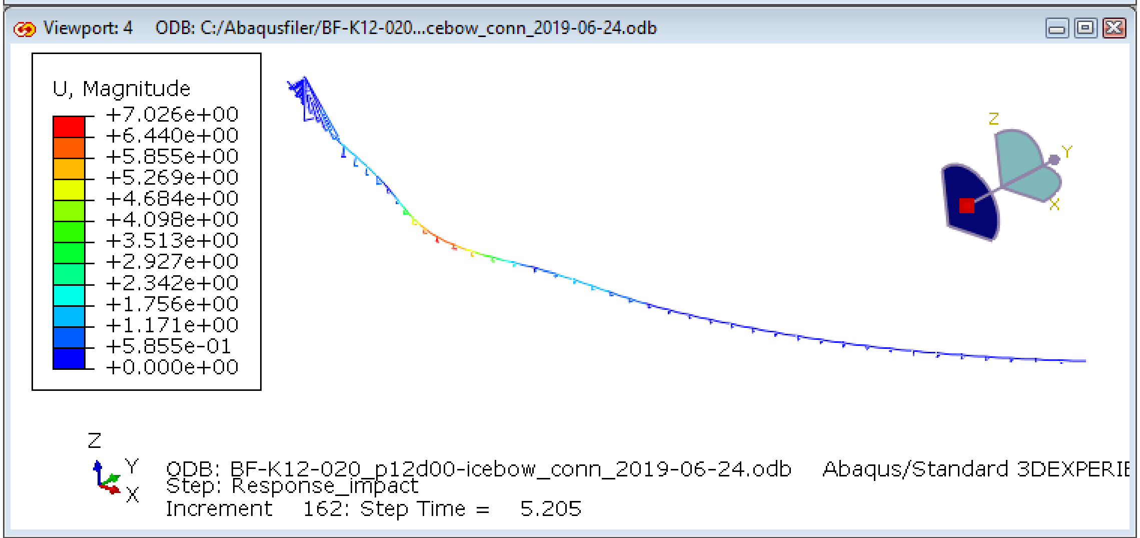
C.4.2 Head-on impacts (0 deg) – ice reinforced bow

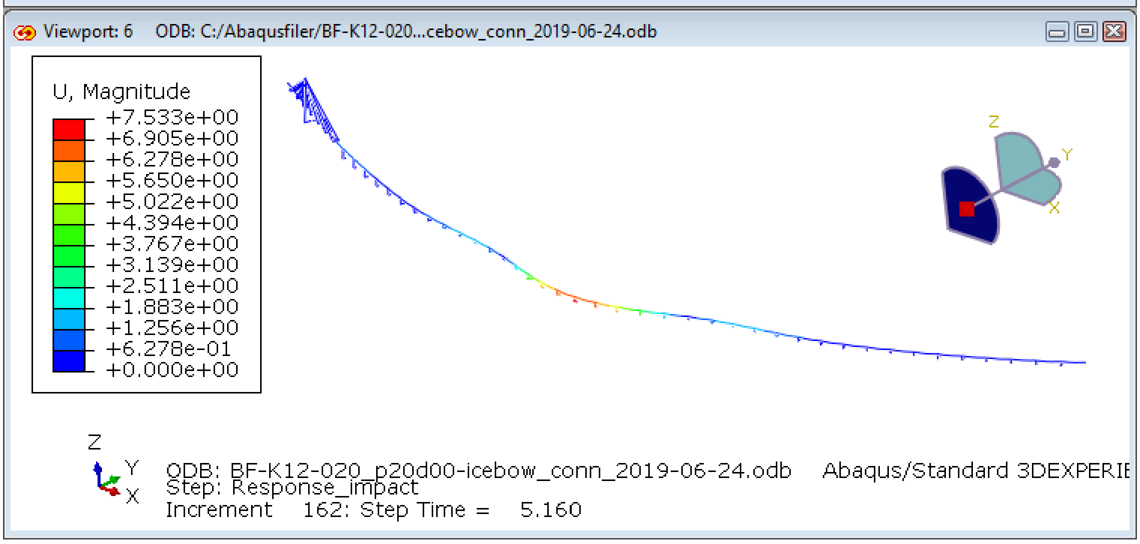
Extended results are shown for the head on impacts on the pontoons in axis 3, 12 and 20. All figures show the same result from the different axis – pontoon 3 impact on top, pontoon 12 impact in the middle and pontoon 20 on the bottom.

The force-indentation curve for the ice-reinforced bow used here is from a 90-degree local impact, so it underestimates the force. But it is mainly used for comparison with the container ship and to see the differences on a more global level between to different impact characteristics. The force-indentation curve is shown in section 3.2.1.

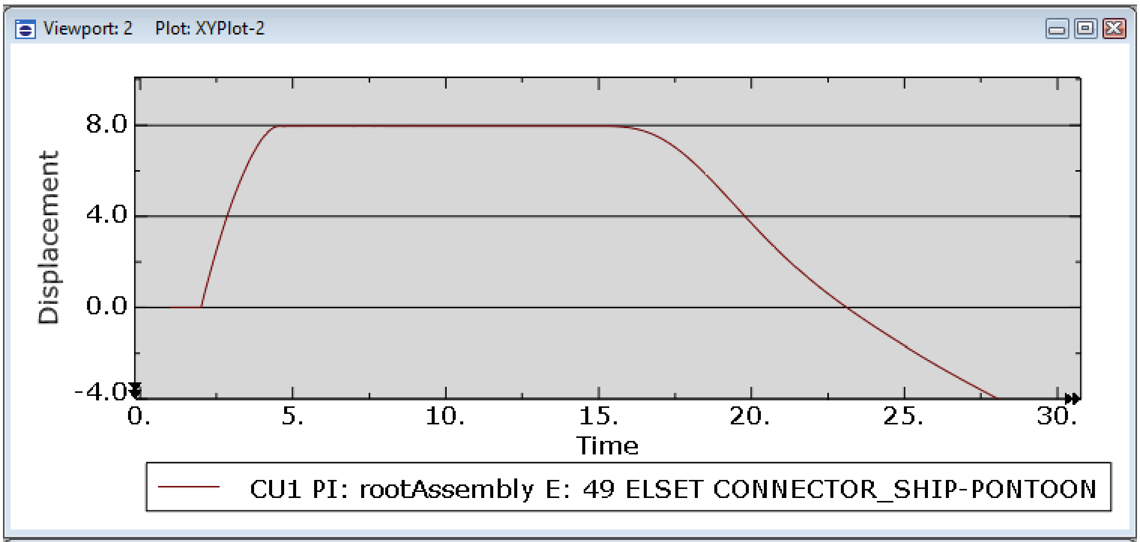
Deformation in m, scale factor 15:

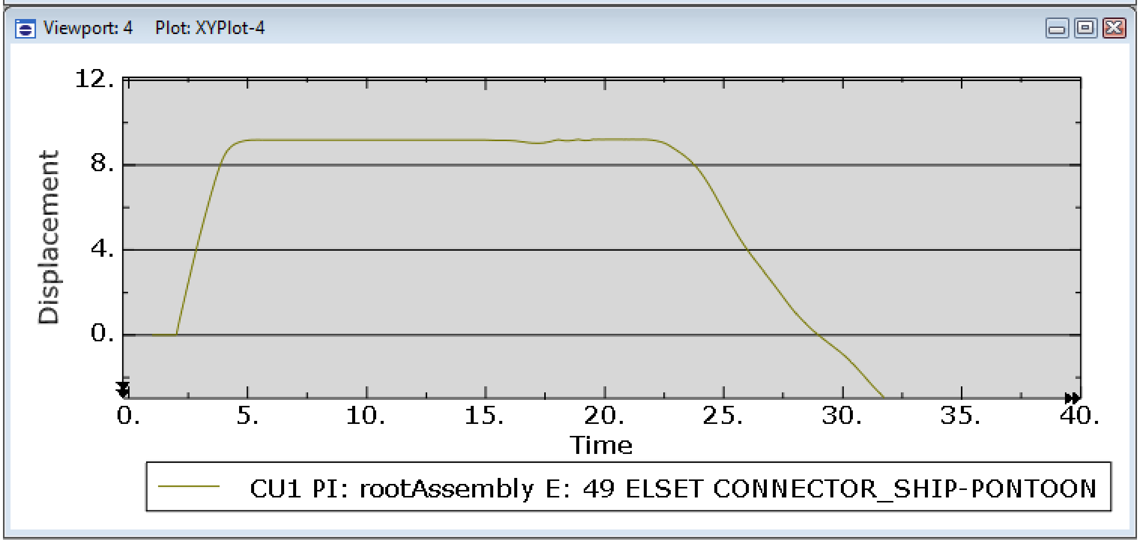


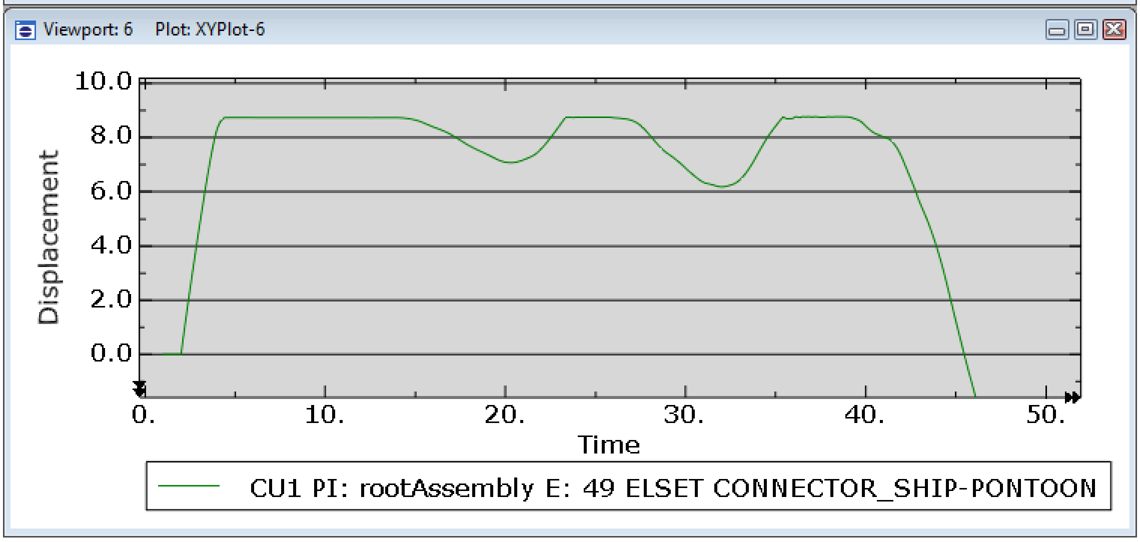




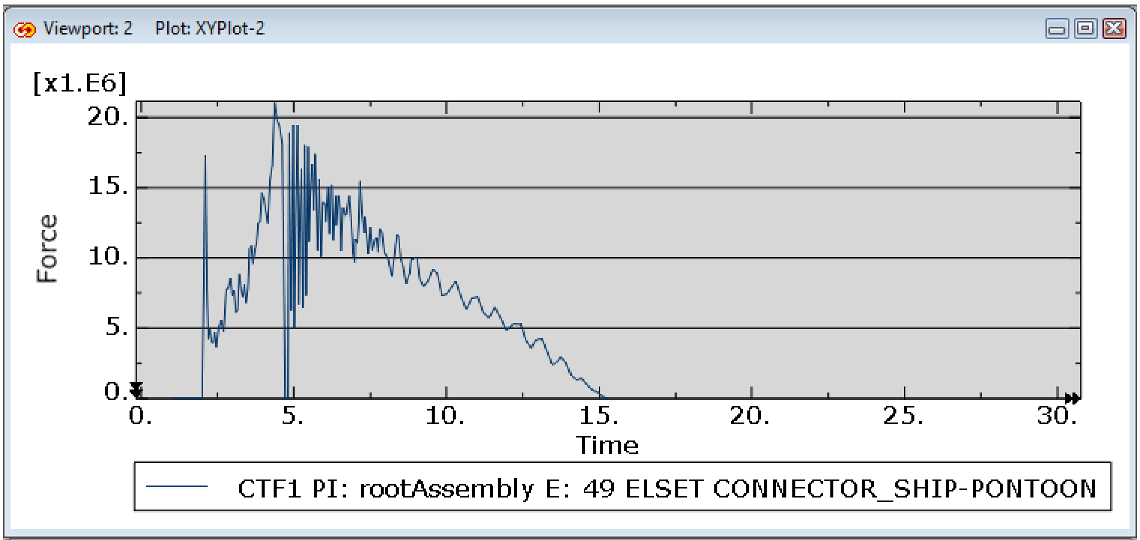
Indentation [m] between ship and pontoon:

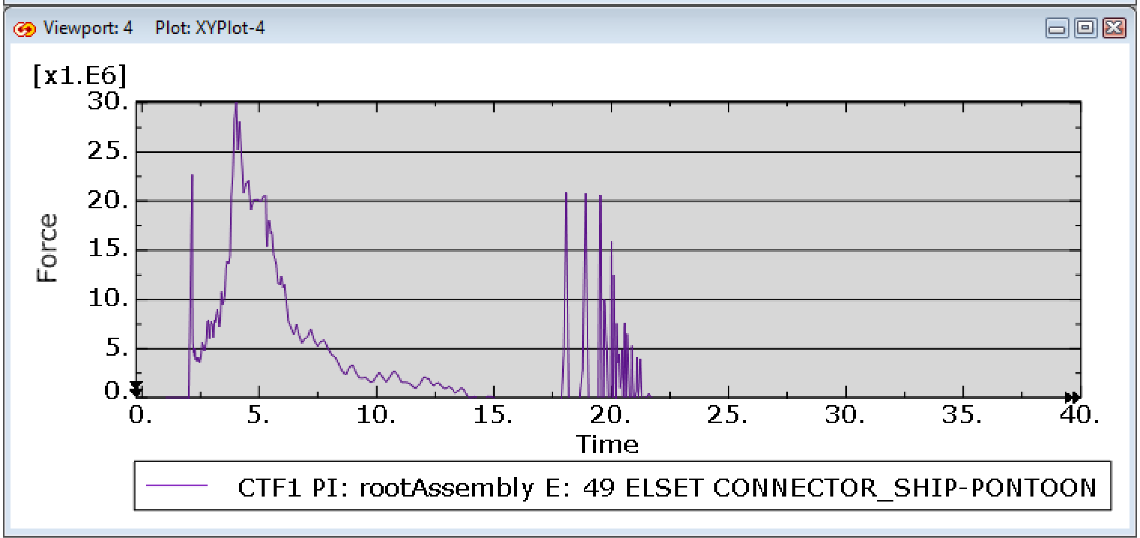


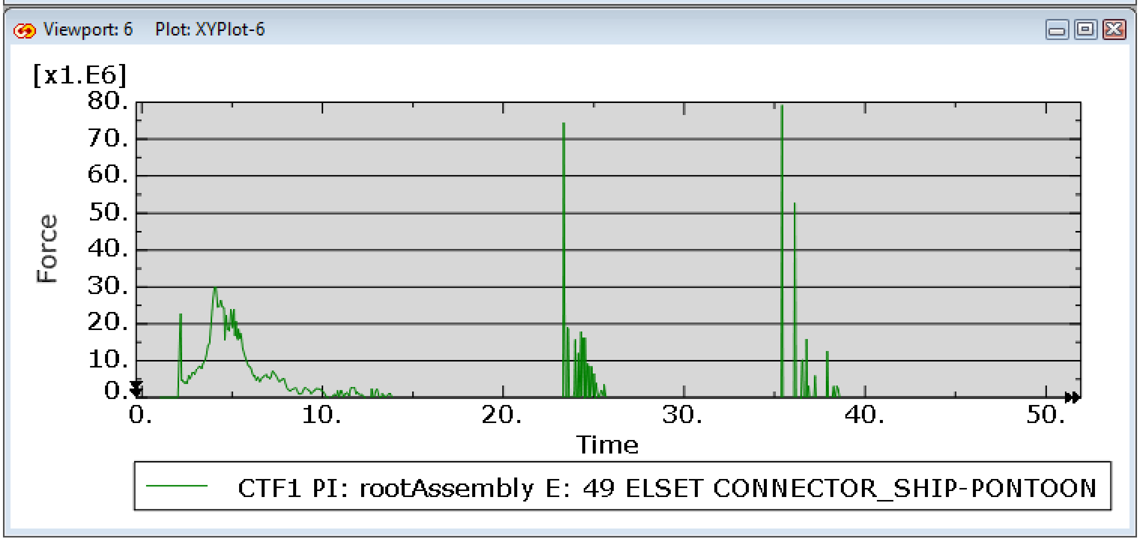




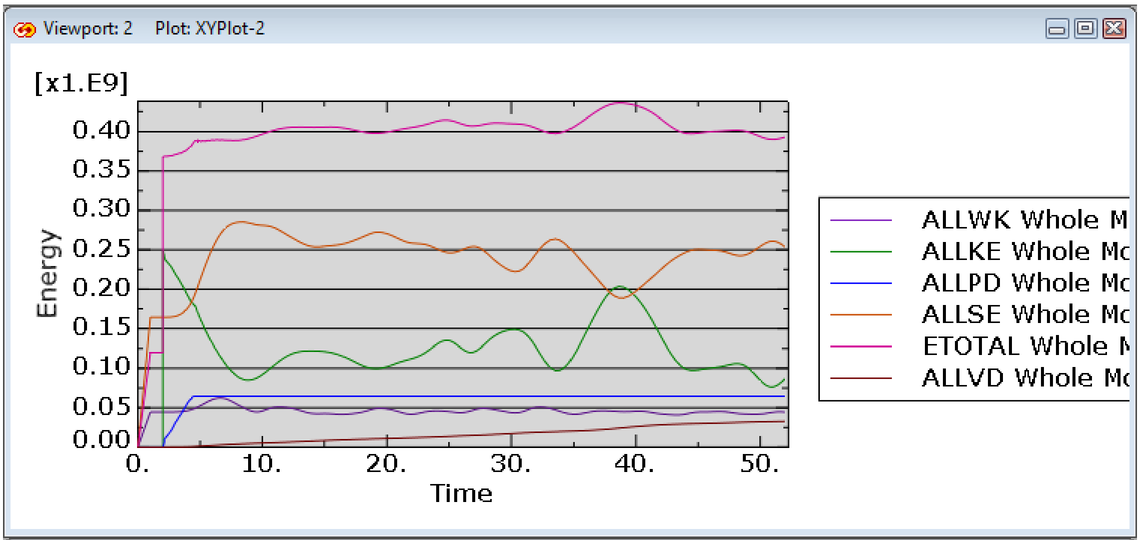
Force [N] between ship and pontoon:

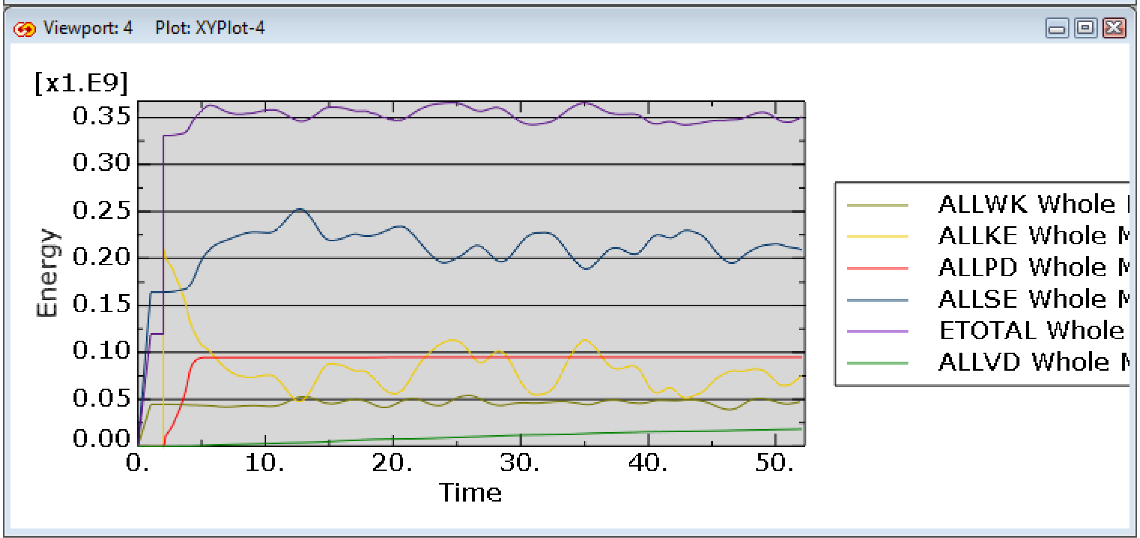


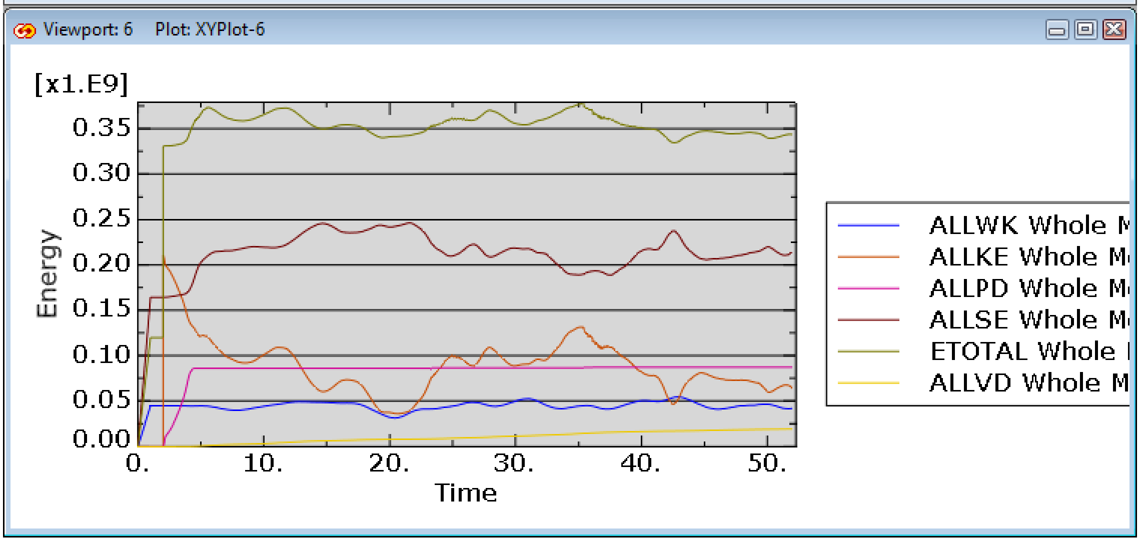




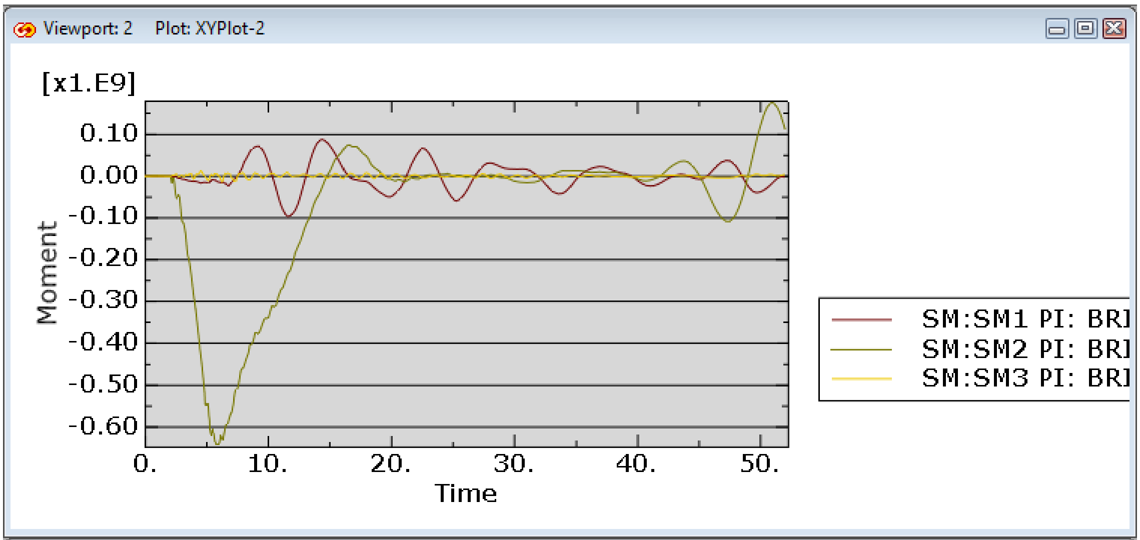
Selected energy plots from analysis [J] (see Appendix A for description of energies):

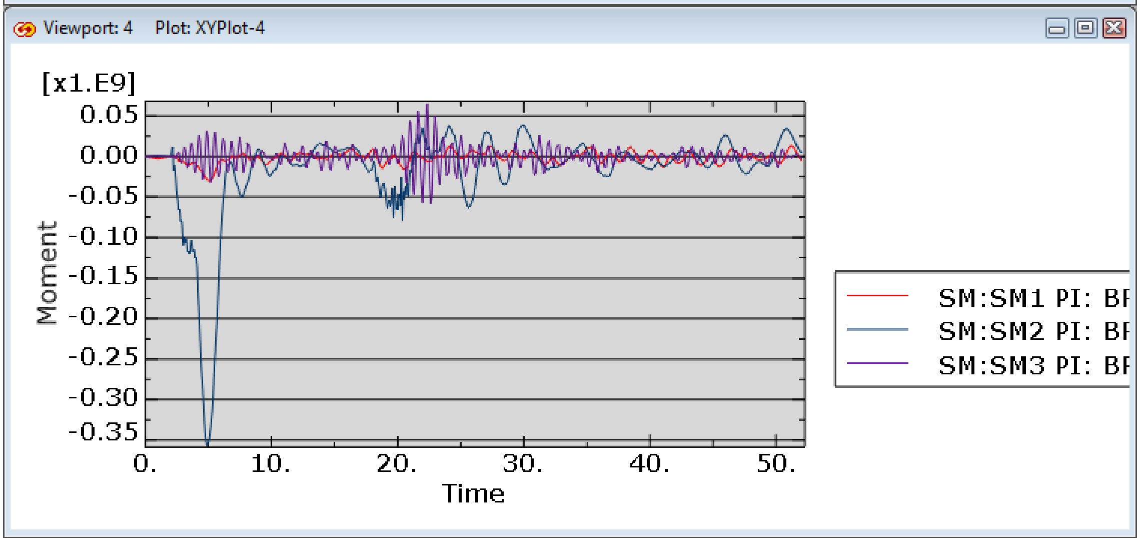


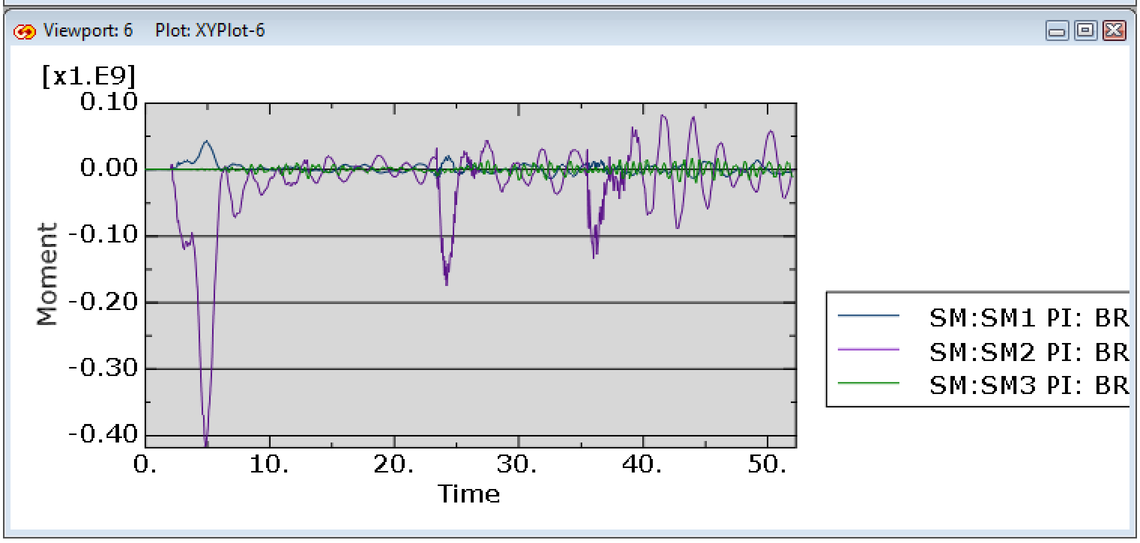




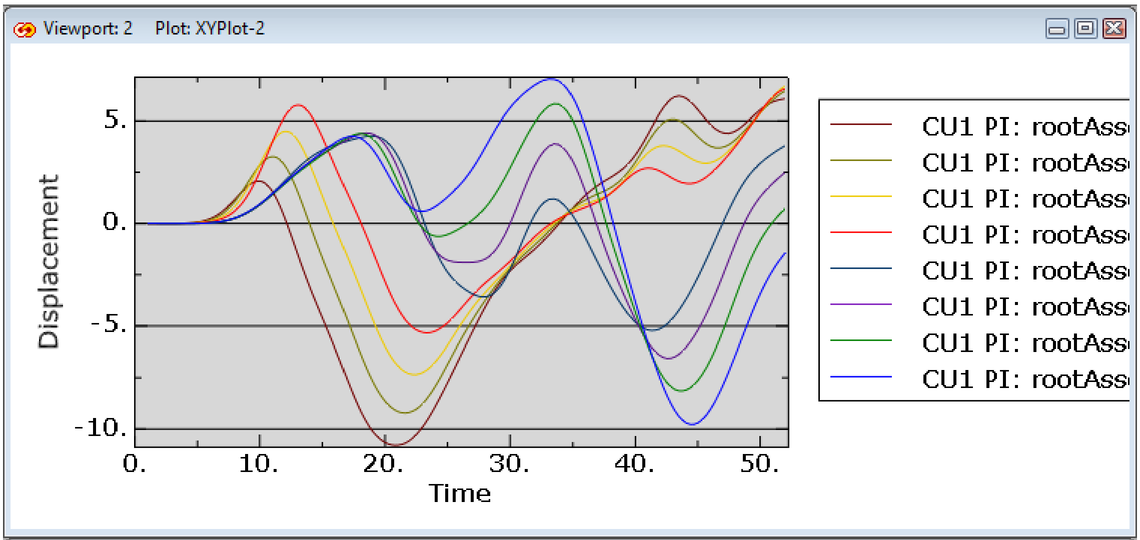
Moments in column top [Nm] (SM1 -weak axis, SM2 – strong axis, SM3 – torsion):

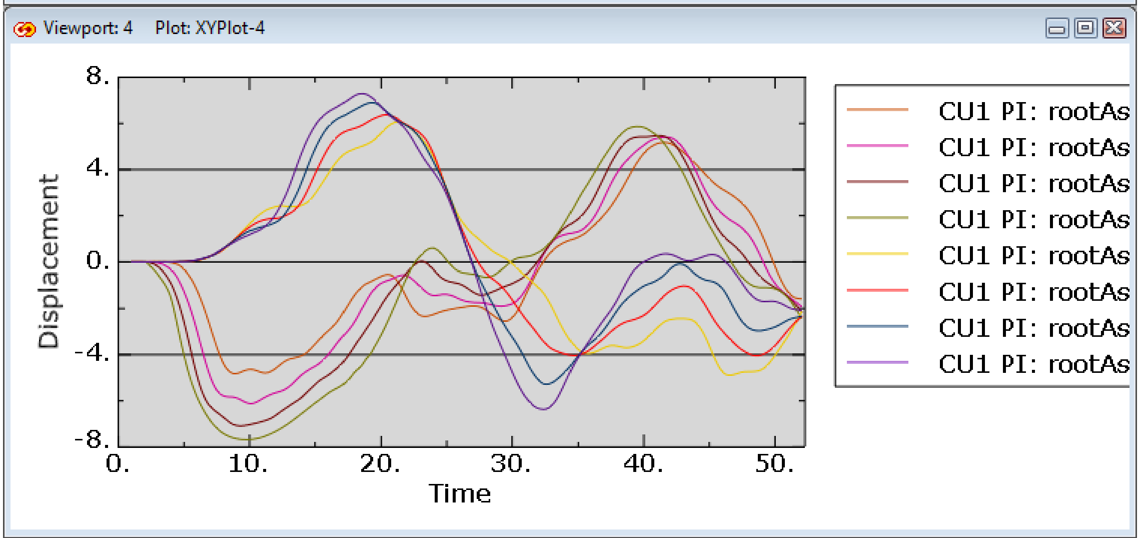


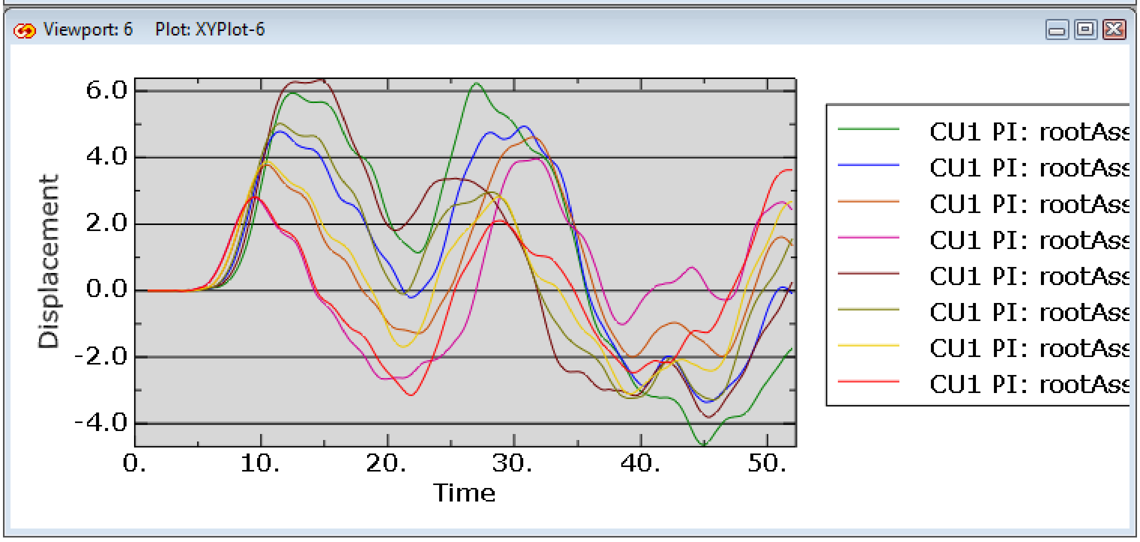




Elongations of anchors [m]:





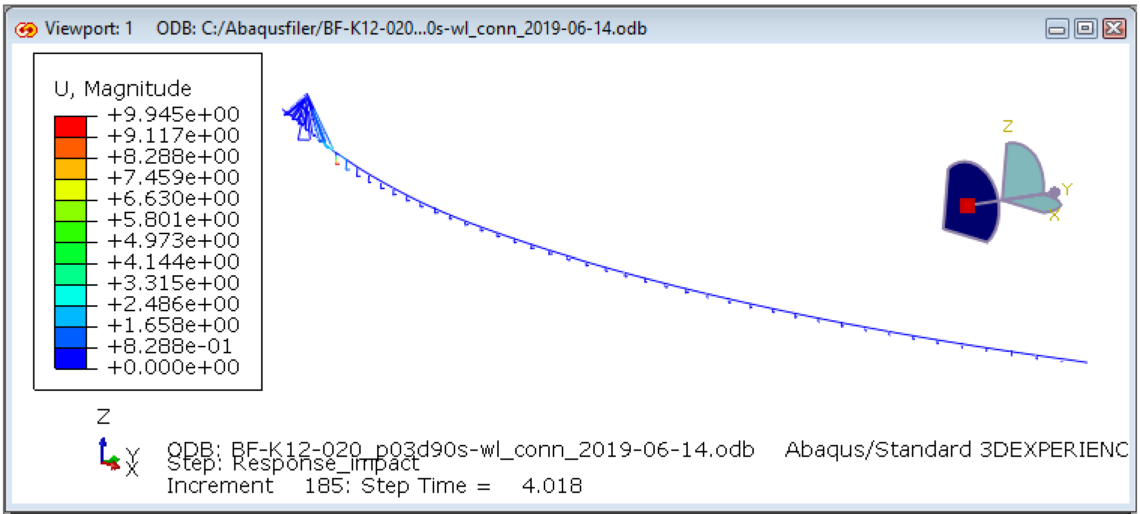


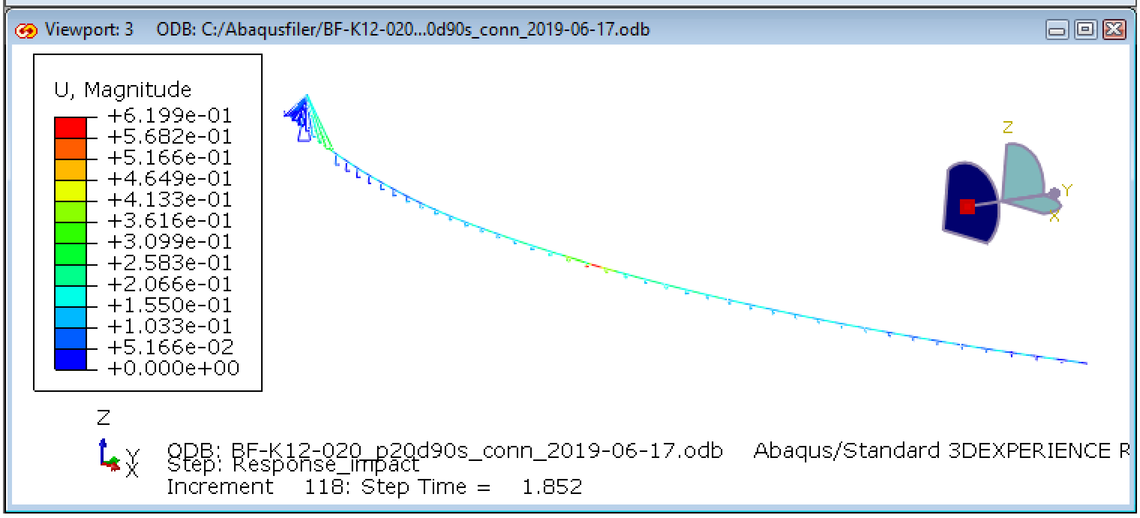
90-degree centric impacts – container ship

Extended results are shown for the 90-degree centric impacts from container ship on the pontoons in axis 3 and 20. The centric impact on axis 12 is not included as it is not expected to give “extreme” results. It is included for the results from the eccentric impact. All figures show the same result from the different axis – pontoon 3 impact on top and pontoon 20 on the bottom. The force-indentation curve is shown in section 3.2.1.

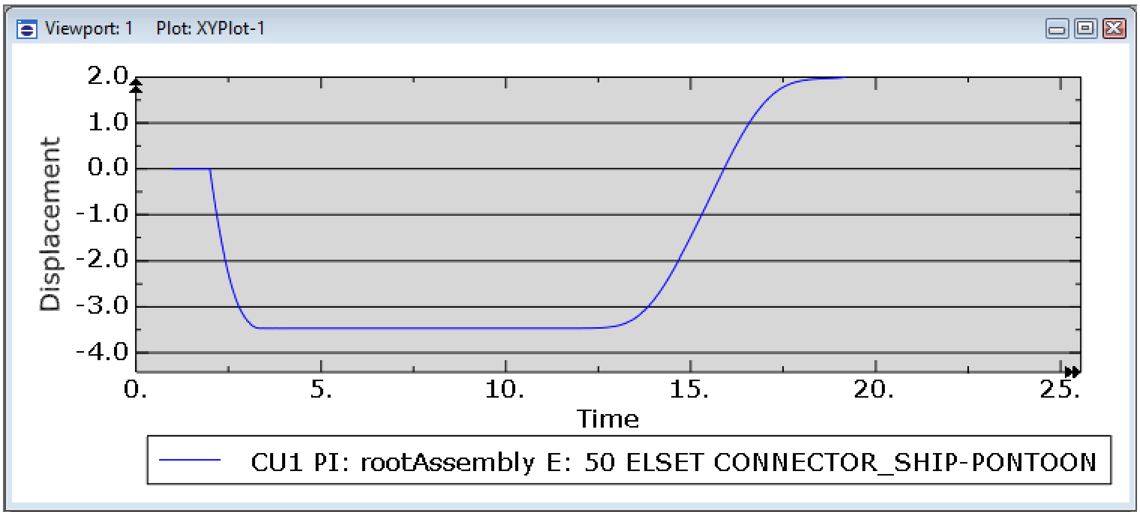
The pontoon 3 analyses are done with a plastic hinge on the column top, see details in the axis 3 90-degree eccentric impact later in this appendix.

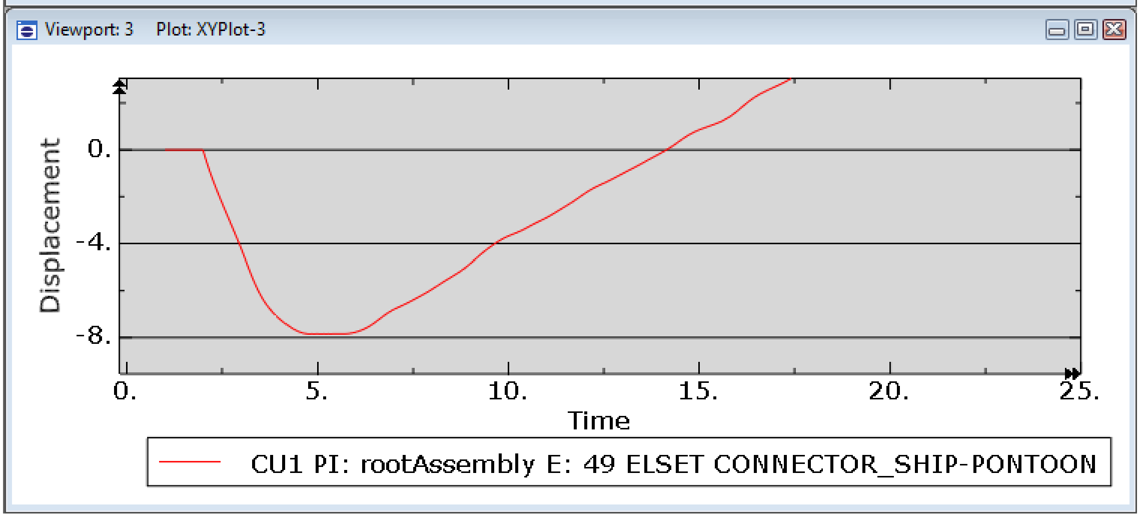
Deformation in m, scale factor 15:



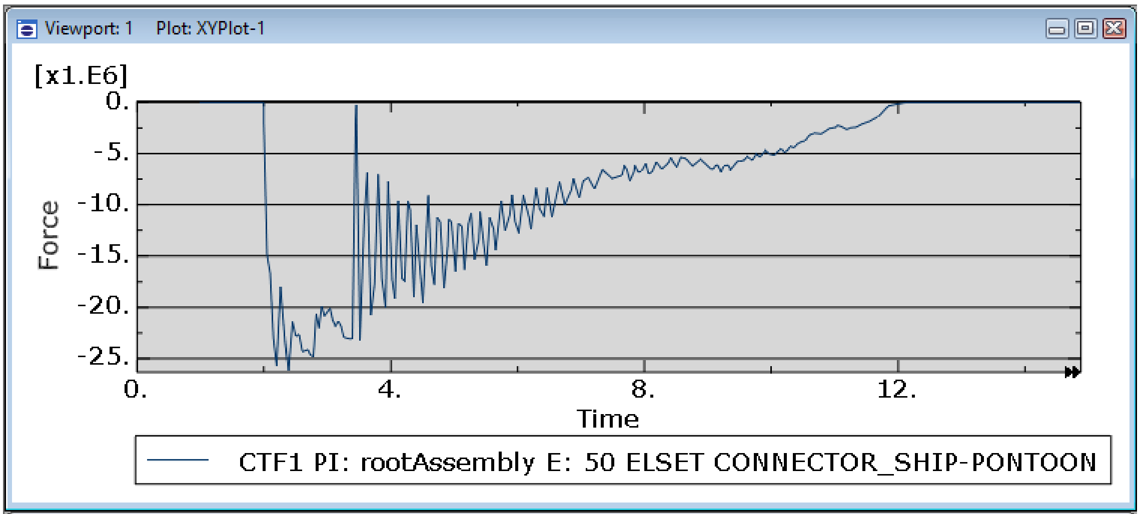


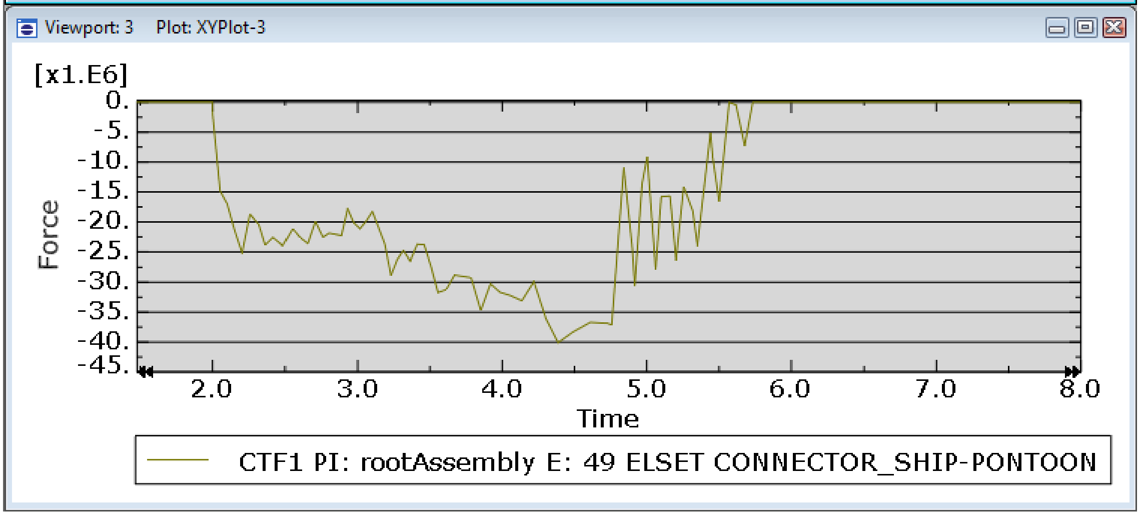
Indentation [m] between ship and pontoon:



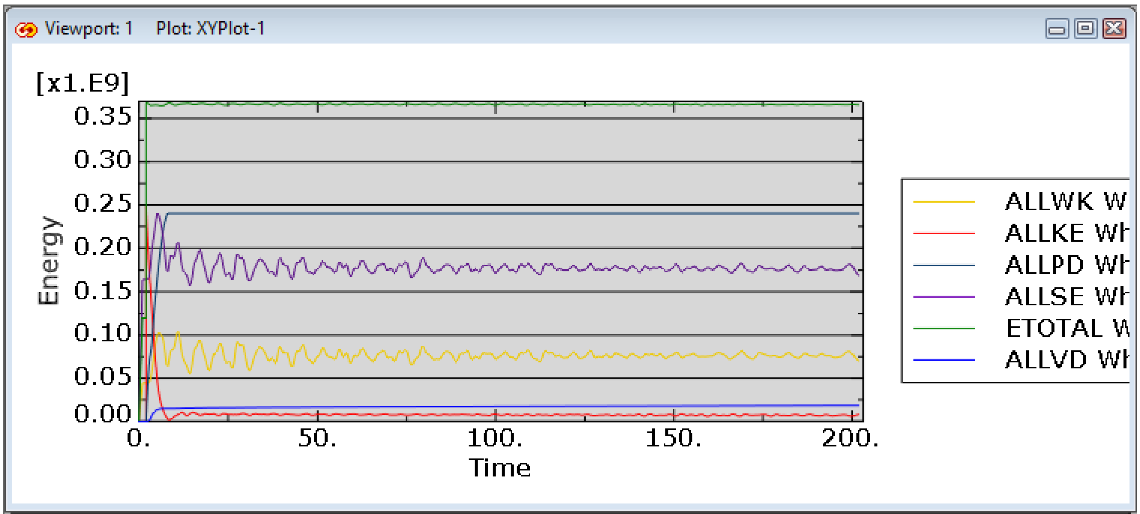


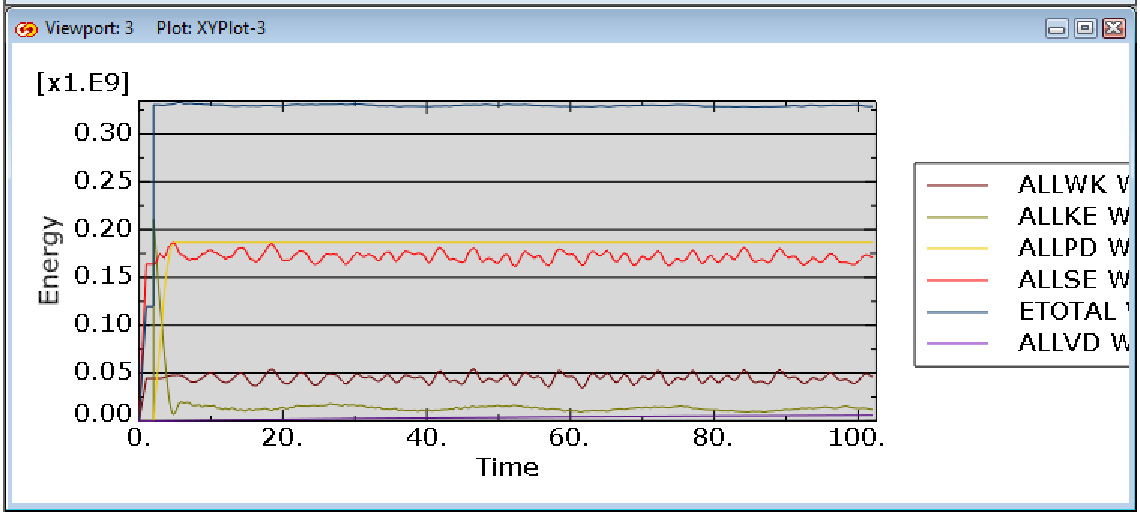
Force [N] between ship and pontoon:



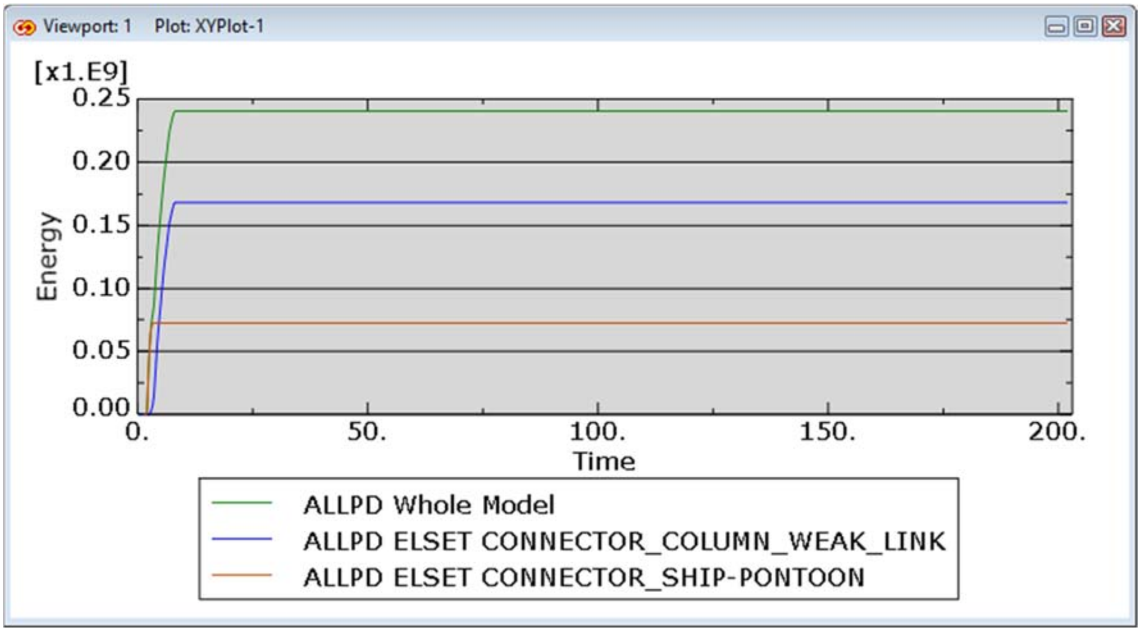


Selected energy plots from analysis [J] (see Appendix A for description of energies):

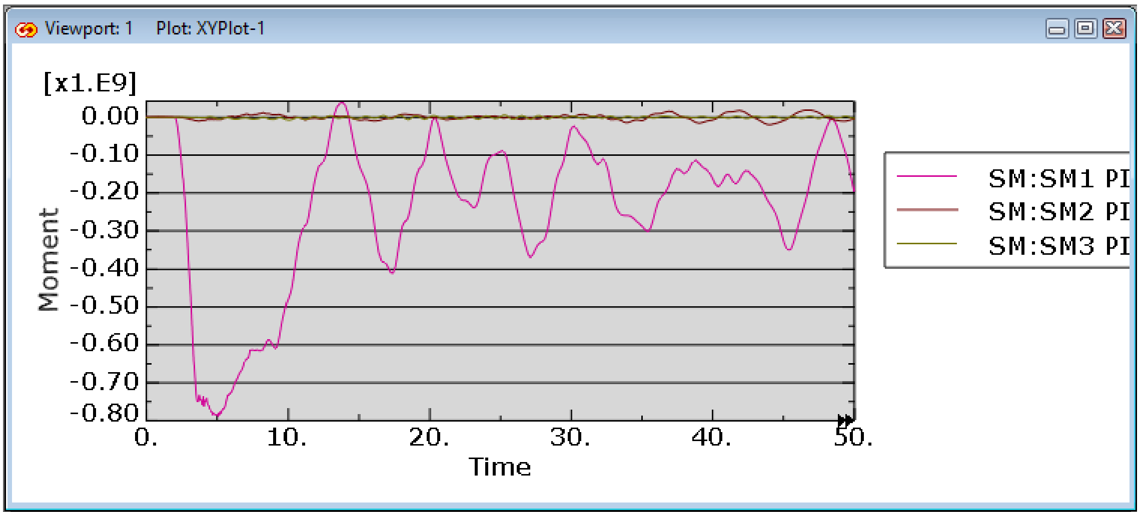


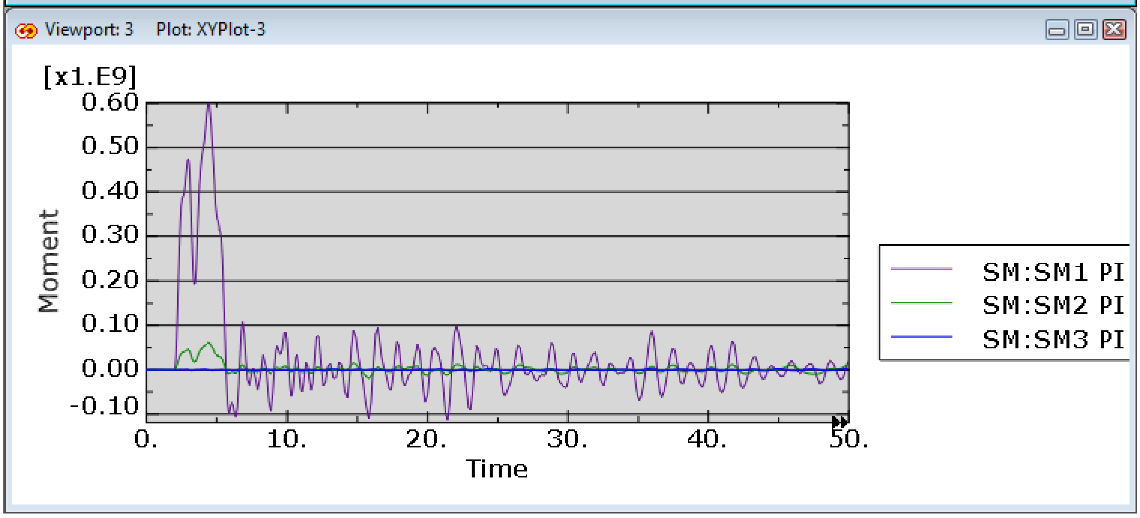


Axis 3 impact – distribution of plastic dissipation between plastic hinge on column top and ship-pontoon damage [J]:



Moments in column top [Nm] (SM1 -weak axis, SM2 – strong axis, SM3 – torsion):



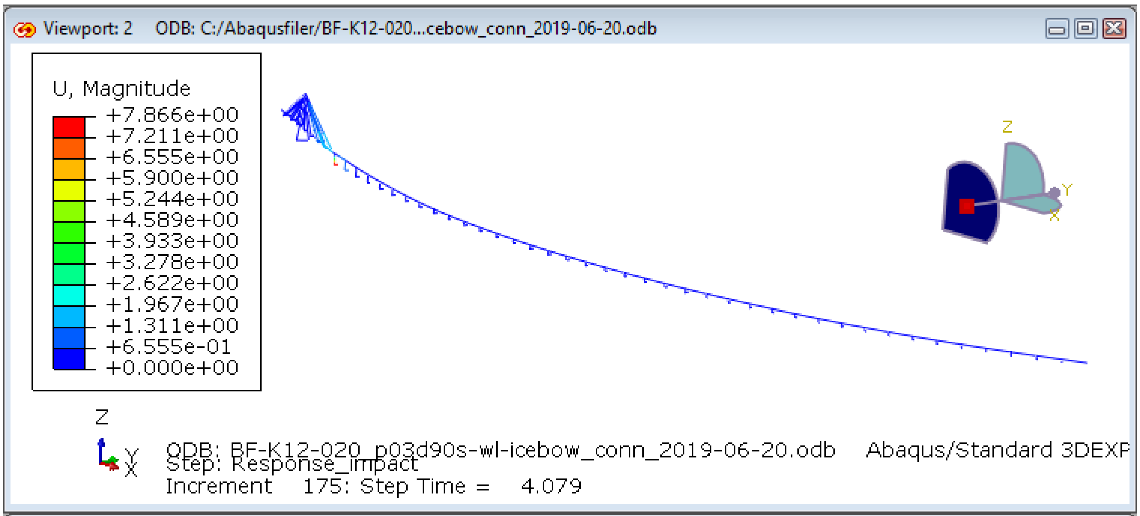


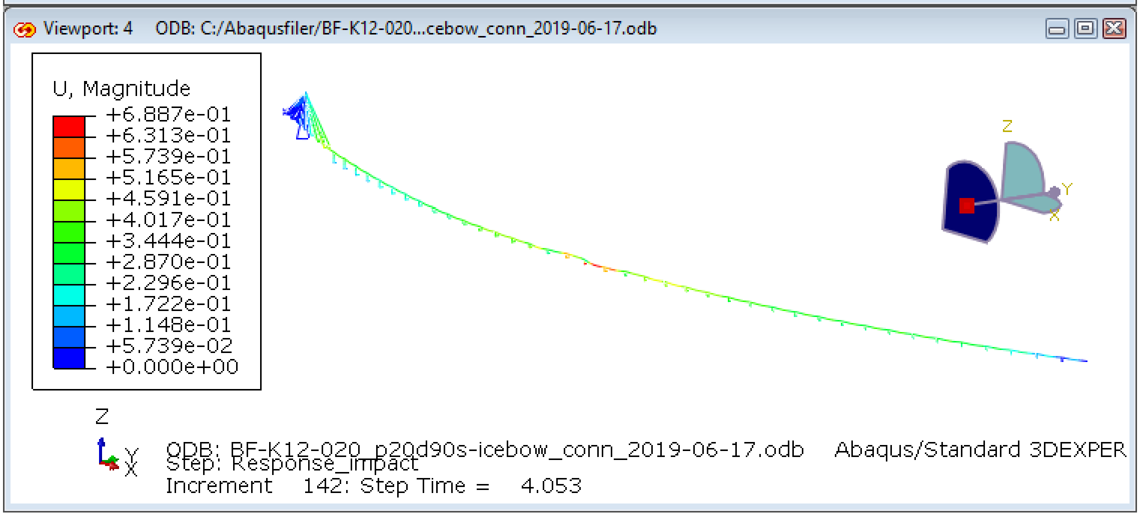
C.4.3 90-degree centric impacts – ice strengthened bow

Extended results are shown for the 90-degree centric impacts from ice strengthened bow on the pontoons in axis 3 and 20. The centric impact on axis 12 is not included as it is not expected to give "extreme" results. It is included for the results from the eccentric impact. All figures show the same result from the different axis – pontoon 3 impact on top and pontoon 20 on the bottom. The force-indentation curve is shown in section 3.2.1.

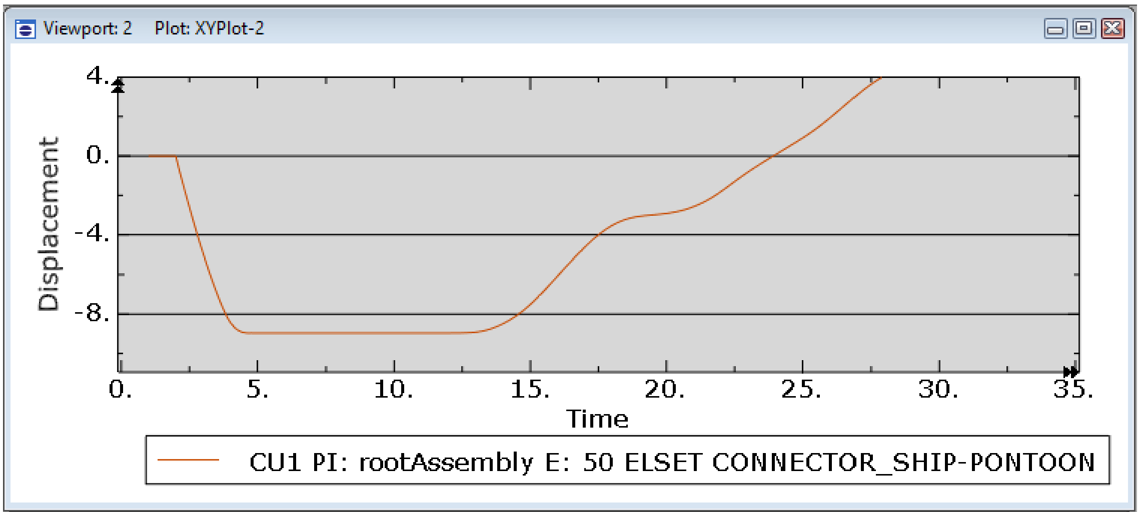
The pontoon 3 analyses are done with a plastic hinge on the column top, see details in the axis 3 90-degree eccentric impact later in this appendix.

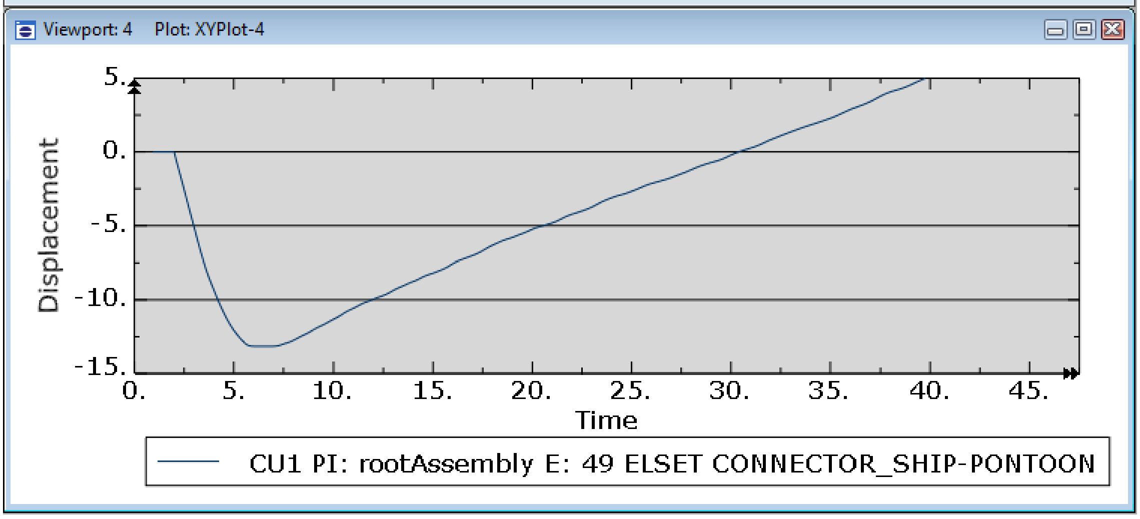
Deformation in m, scale factor 15:



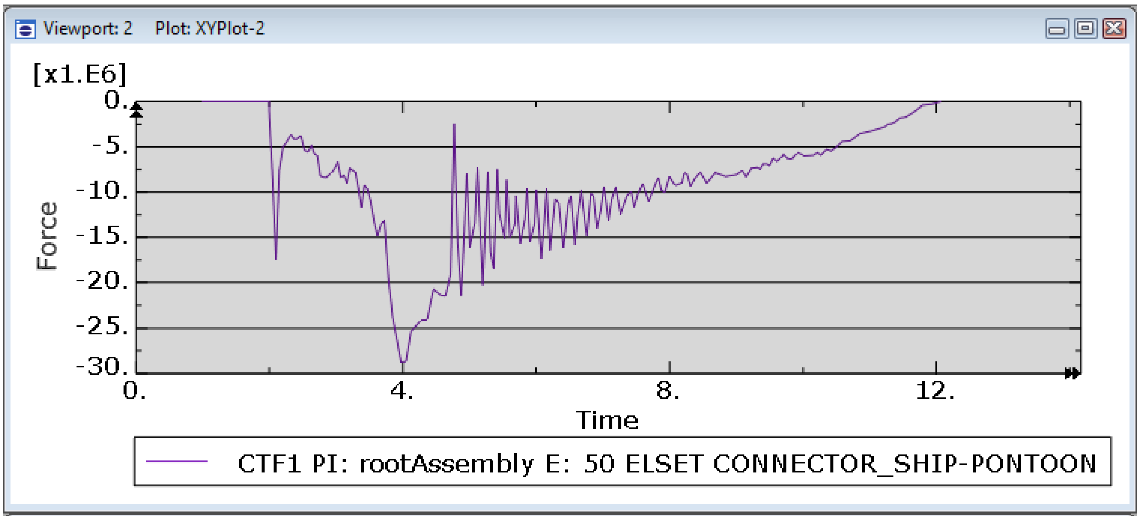


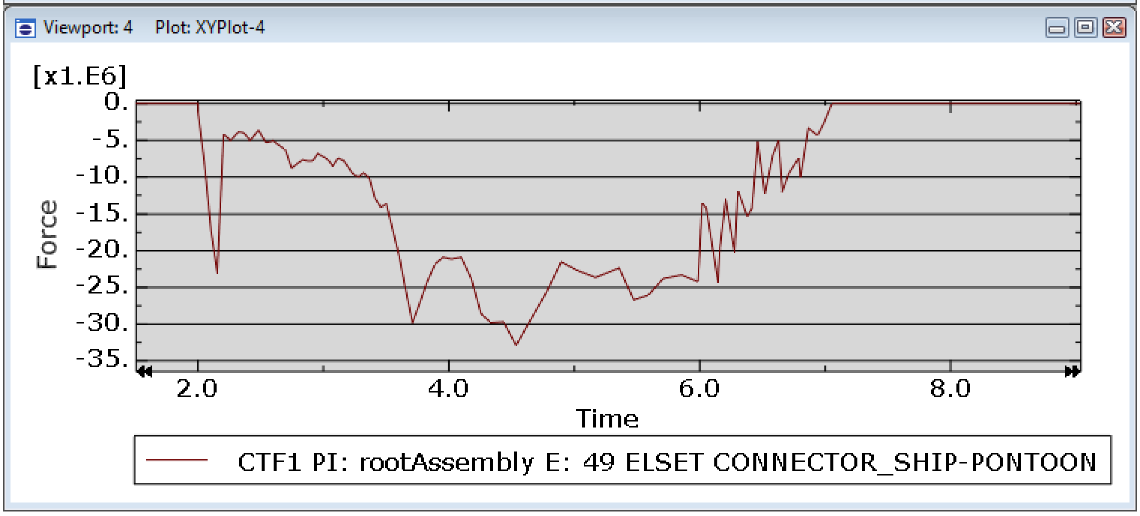
Indentation [m] between ship and pontoon:



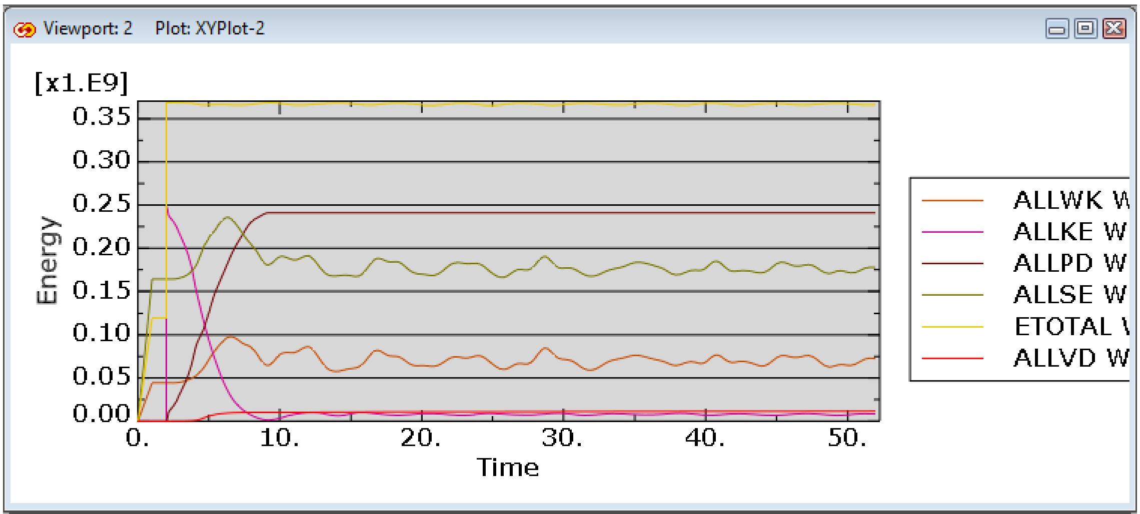


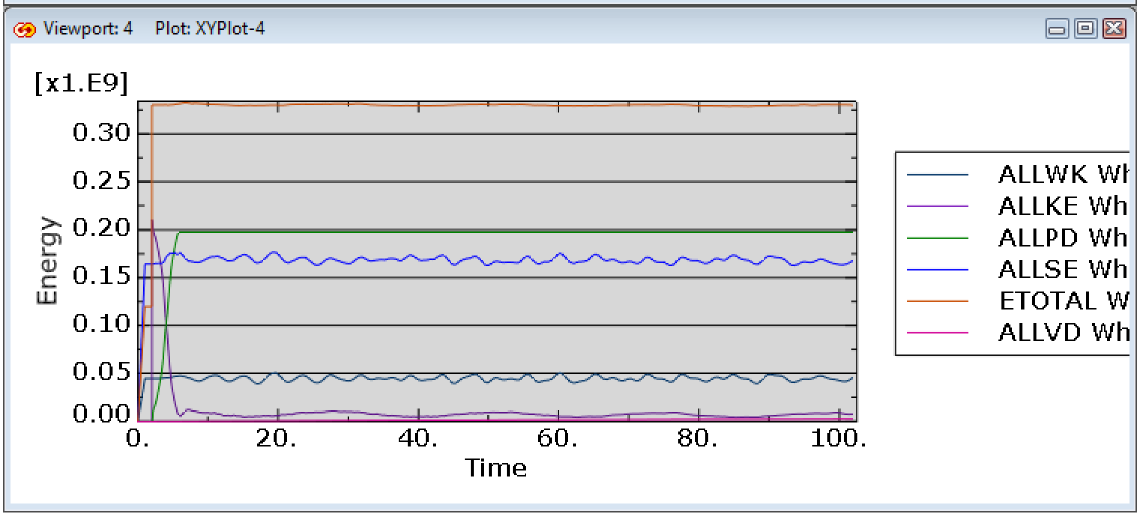
Force [N] between ship and pontoon:



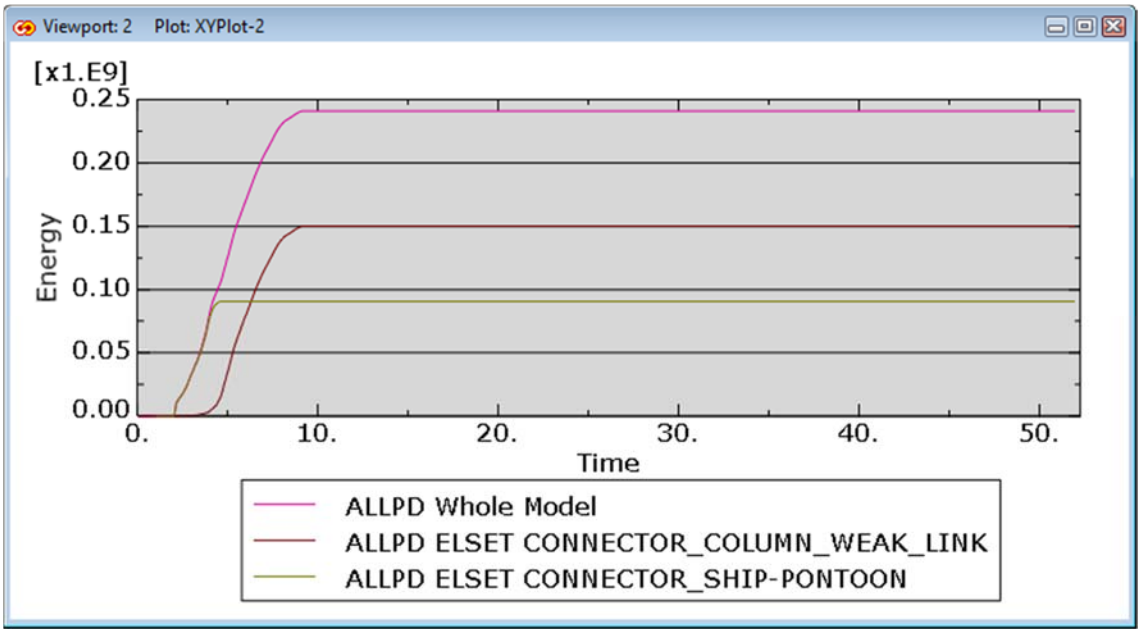


Selected energy plots from analysis [J] (see Appendix A for description of energies):

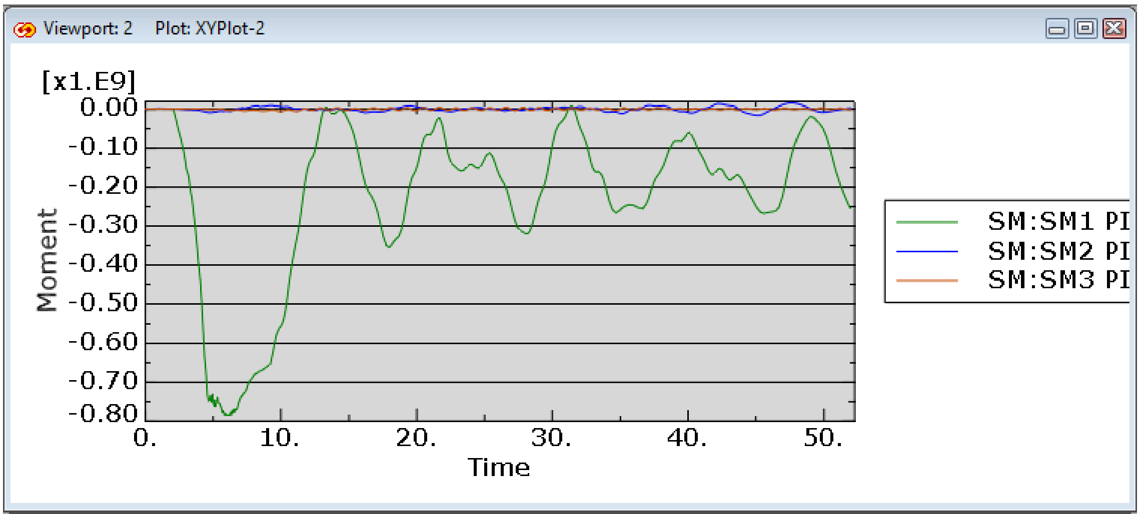


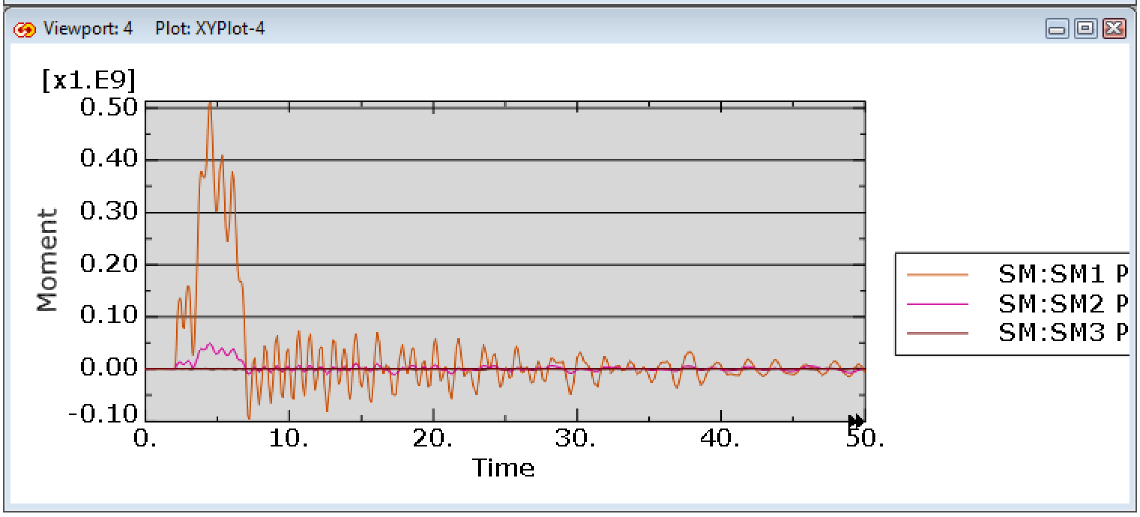


Axis 3 impact – distribution of plastic dissipation between plastic hinge on column top and ship-pontoon damage [J]:



Moments in column top [Nm] (SM1 -weak axis, SM2 – strong axis, SM3 – torsion):





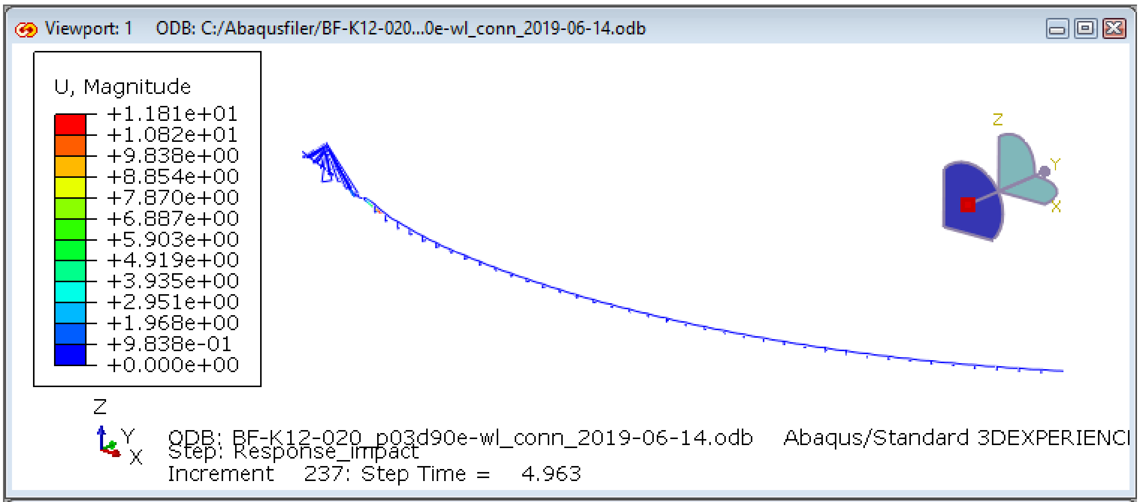
C.4.4 90-degree eccentric impacts – container ship

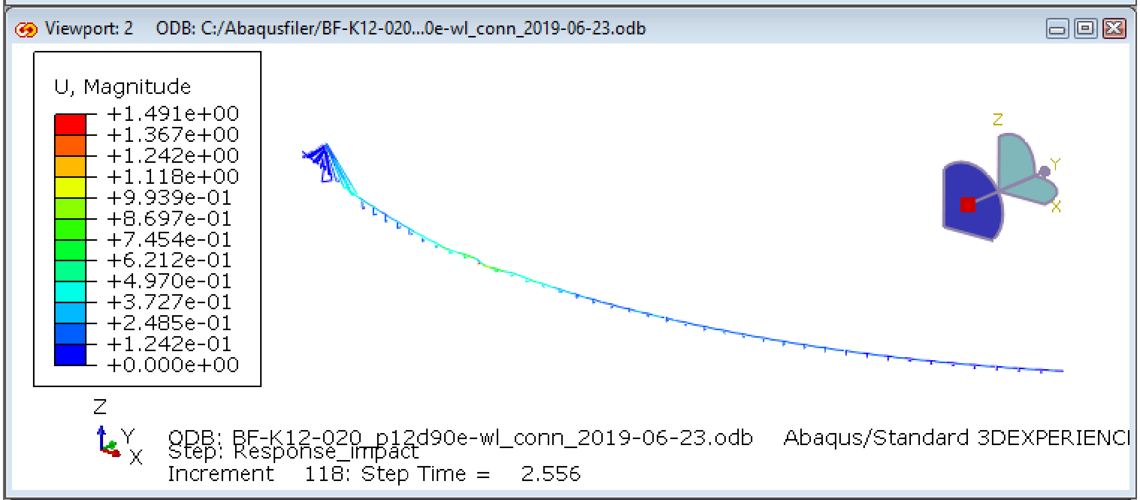
The 90-degree eccentric impacts are performed on the container ships only, as it is maximum forces/moments in columns that are the interesting output from these cases. The eccentric impact is softer than the centric impact and will not give larger indentations between ship and pontoon.

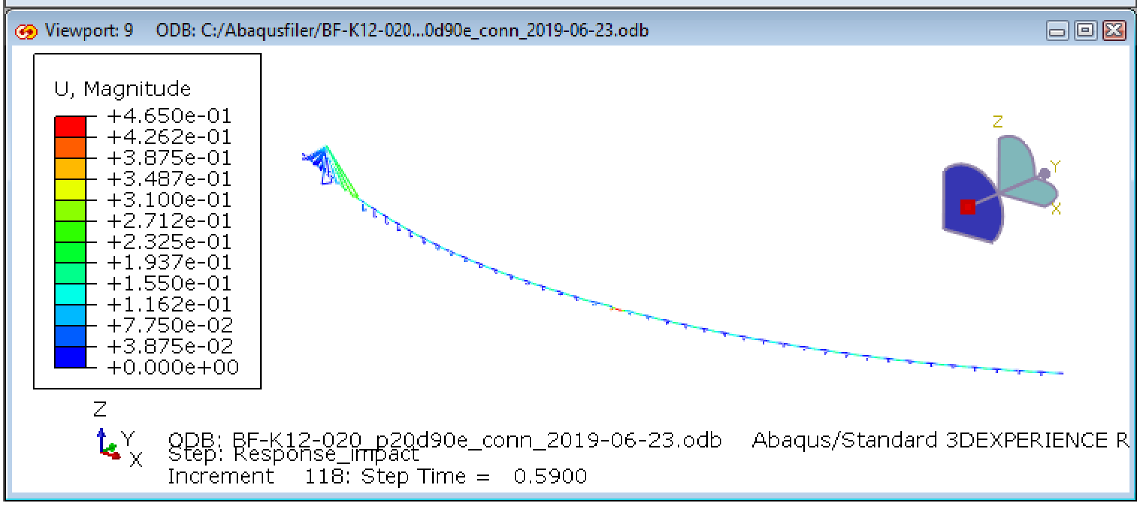
Extended results are shown for the 90-degree eccentric impacts from container ship on the pontoons in axis 3 and 20. All figures show the same result from the different axis – pontoon 3 impact on top, pontoon 12 impact in the middle and pontoon 20 on the bottom. The force-indentation curve is shown in section 3.2.1.

The pontoon 3 and 12 analyses are done with a plastic hinge on the column top, see details in the axis 3 90-degree eccentric impact later in this appendix.

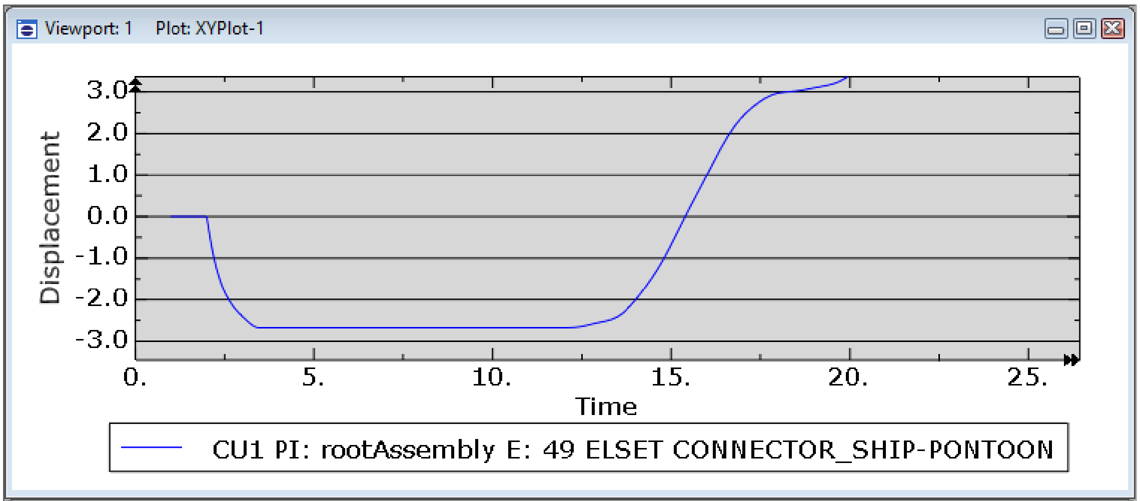
Deformation in m, scale factor 15:

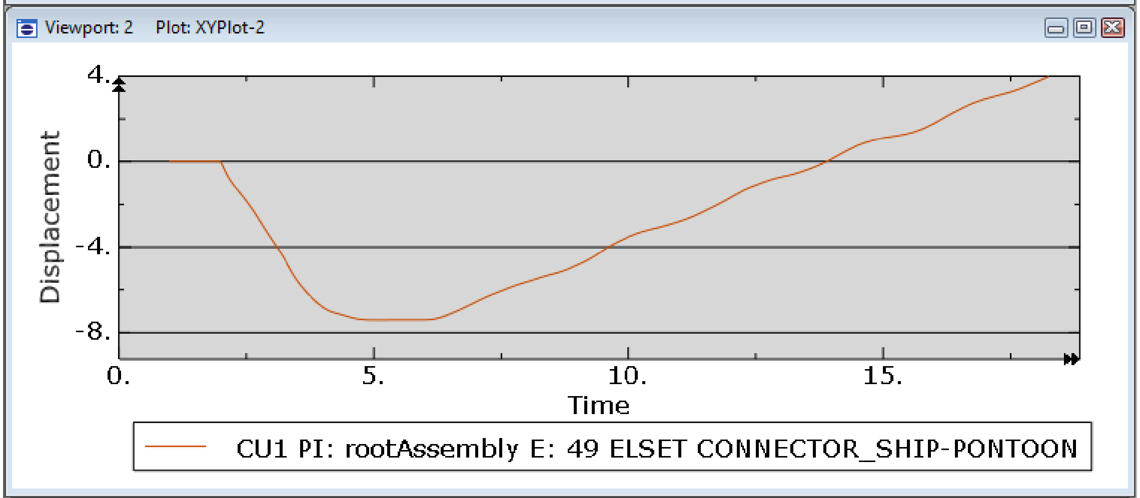


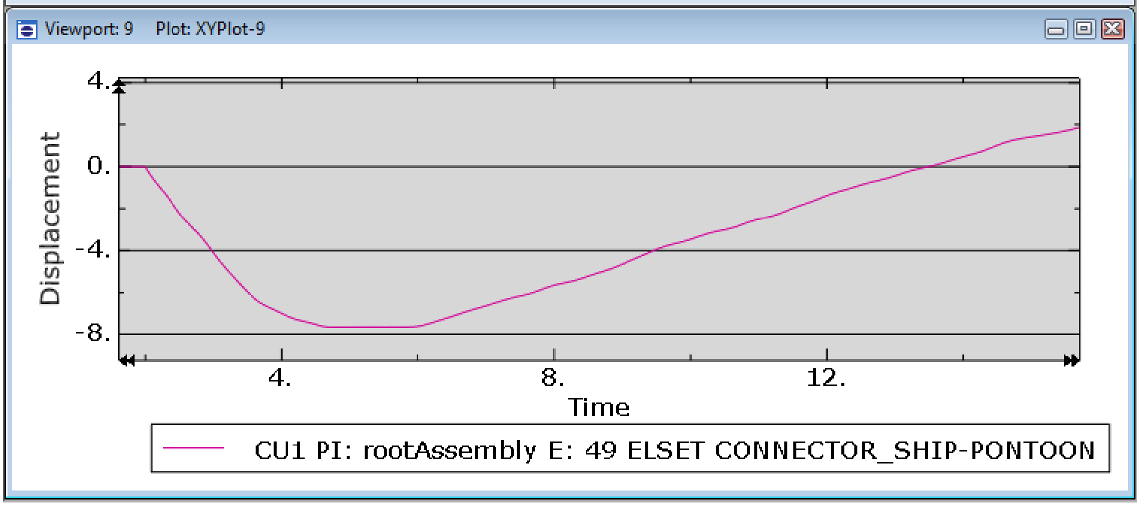




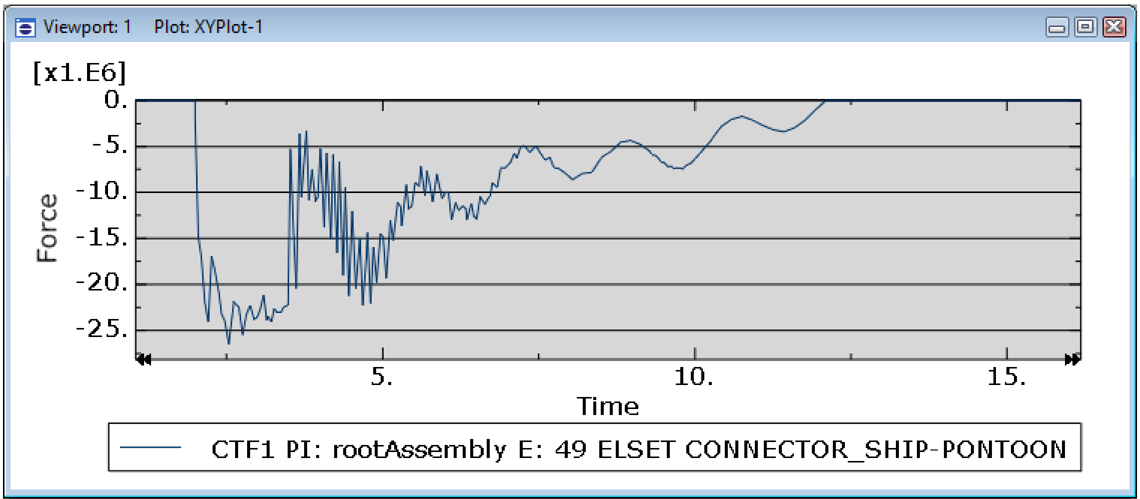
Indentation [m] between ship and pontoon:

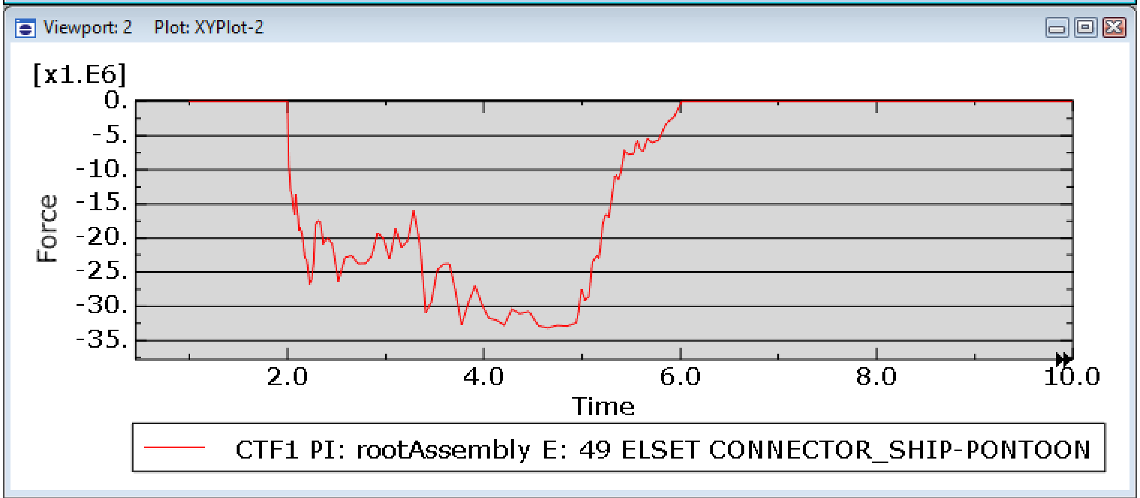


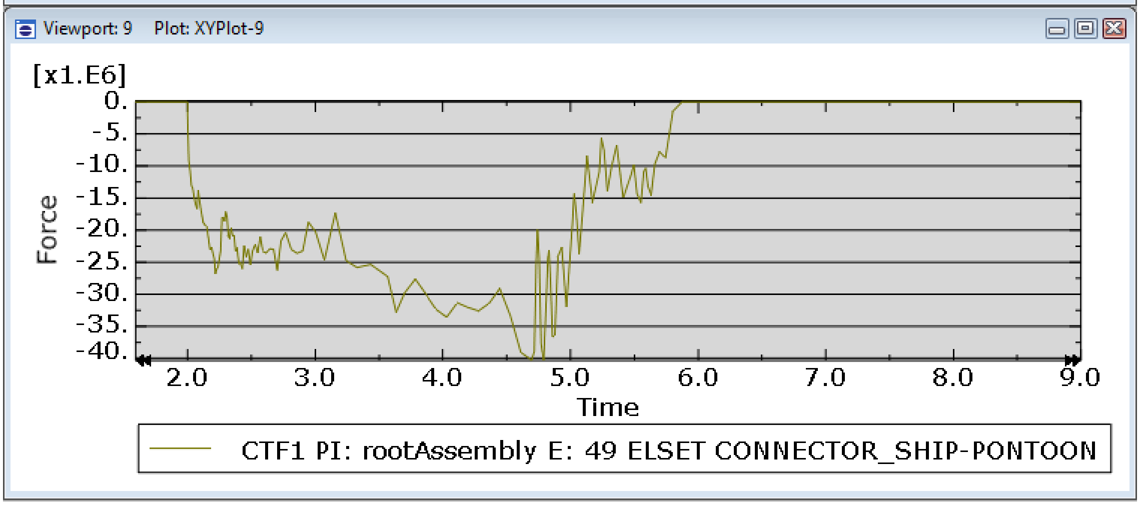




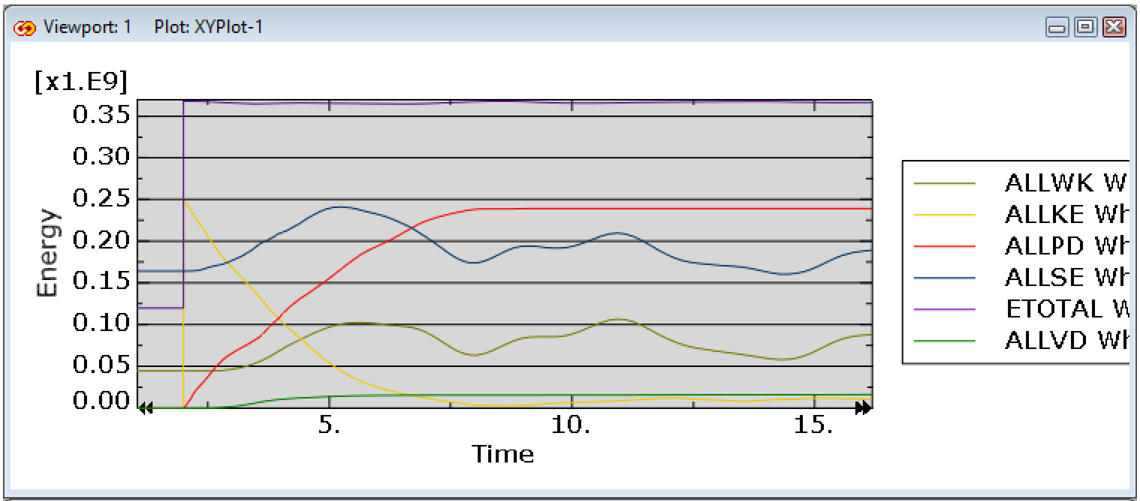
Force [N] between ship and pontoon:

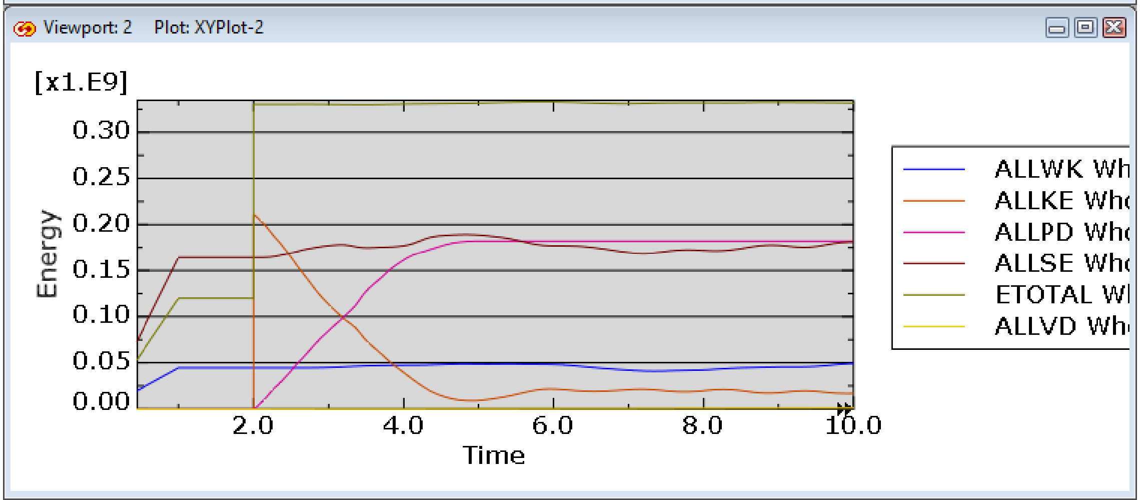


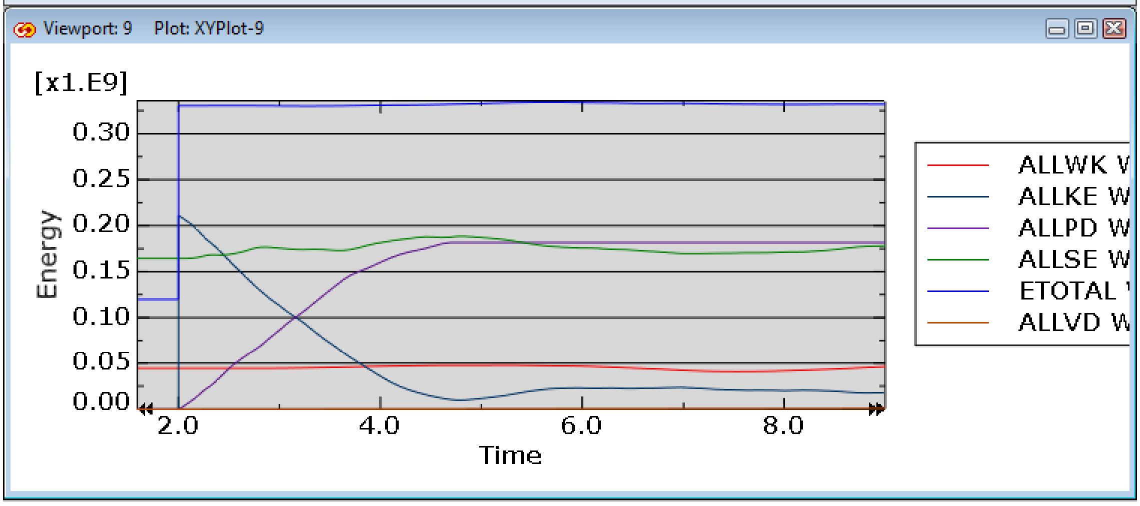




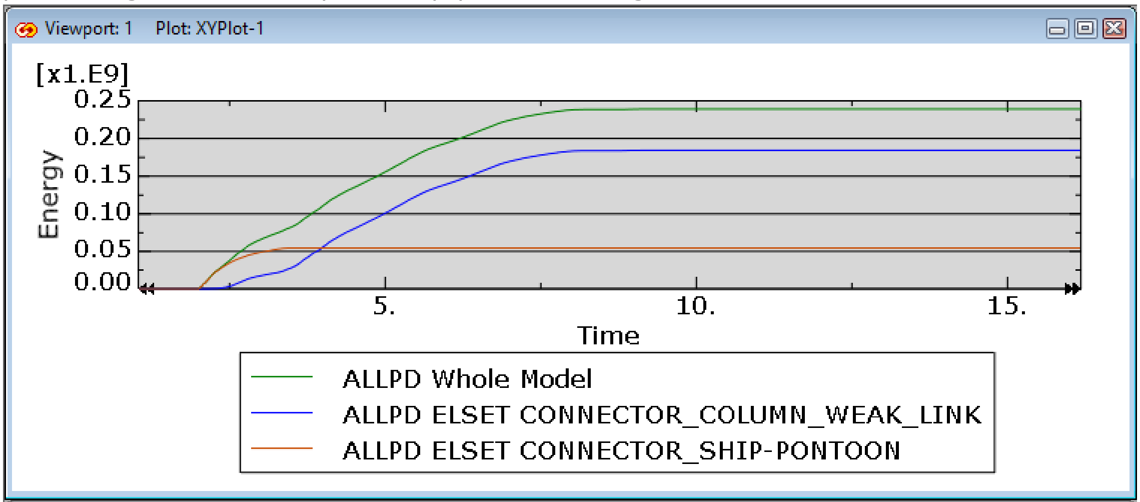
Selected energy plots from analysis [J] (see Appendix A for description of energies):

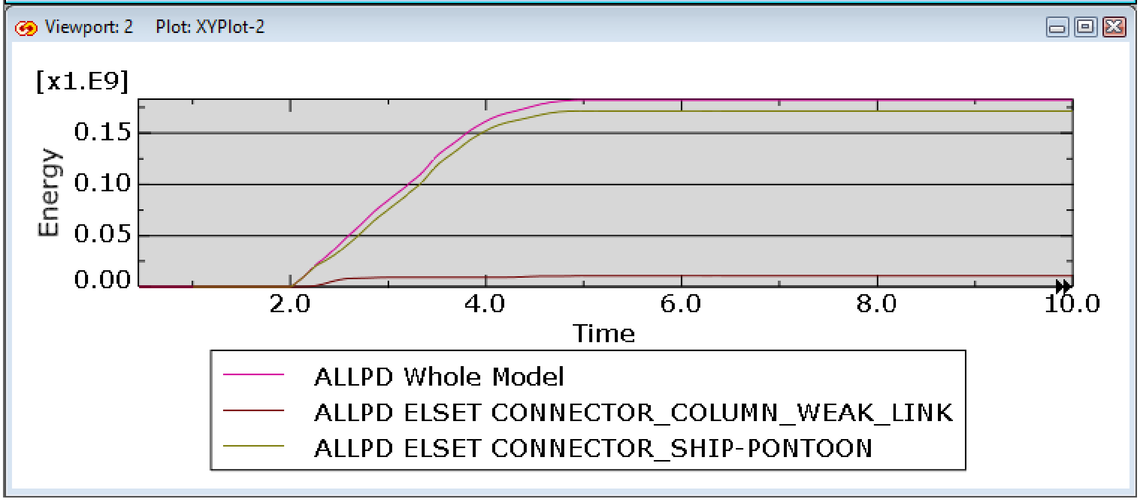




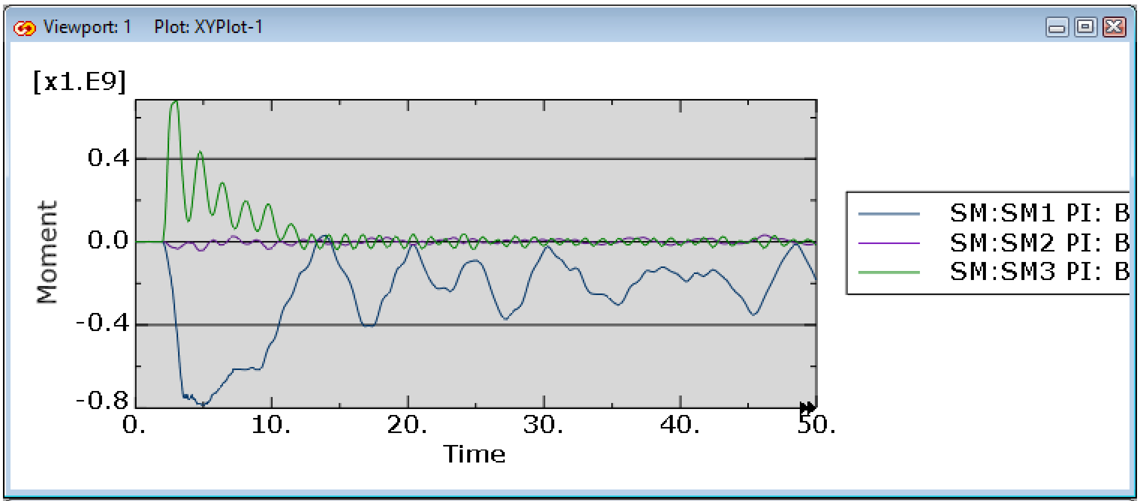


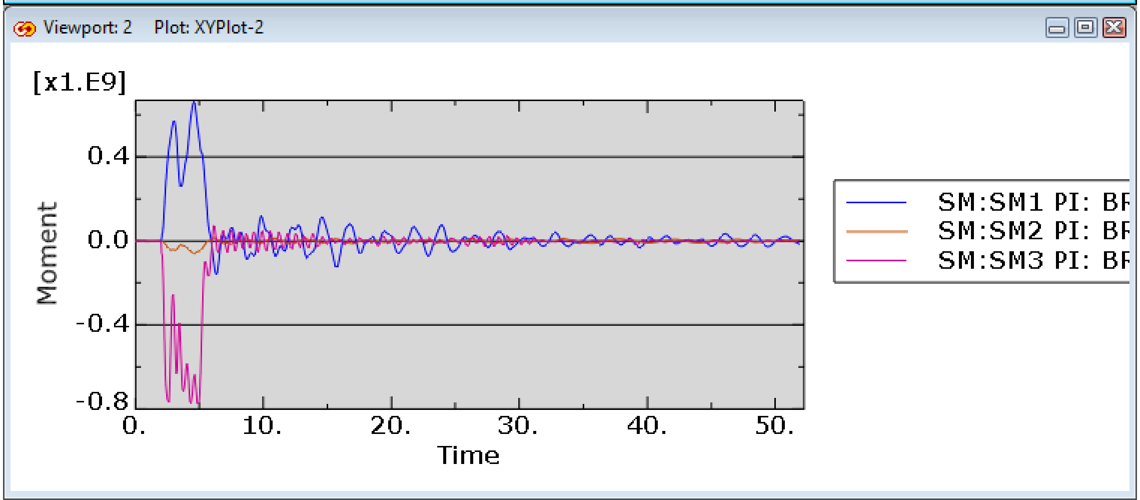
Axis 3 and 12 impacts (with plastic hinges) – distribution of plastic dissipation between plastic hinge on column top and ship-pontoon damage [J]:

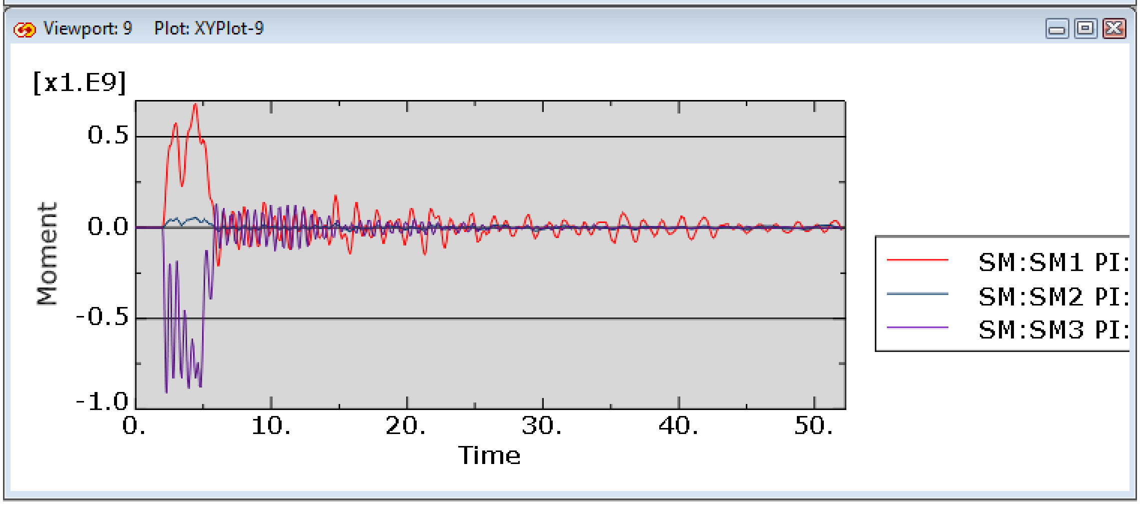




Moments in column top [Nm] (SM1 -weak axis, SM2 – strong axis, SM3 – torsion):



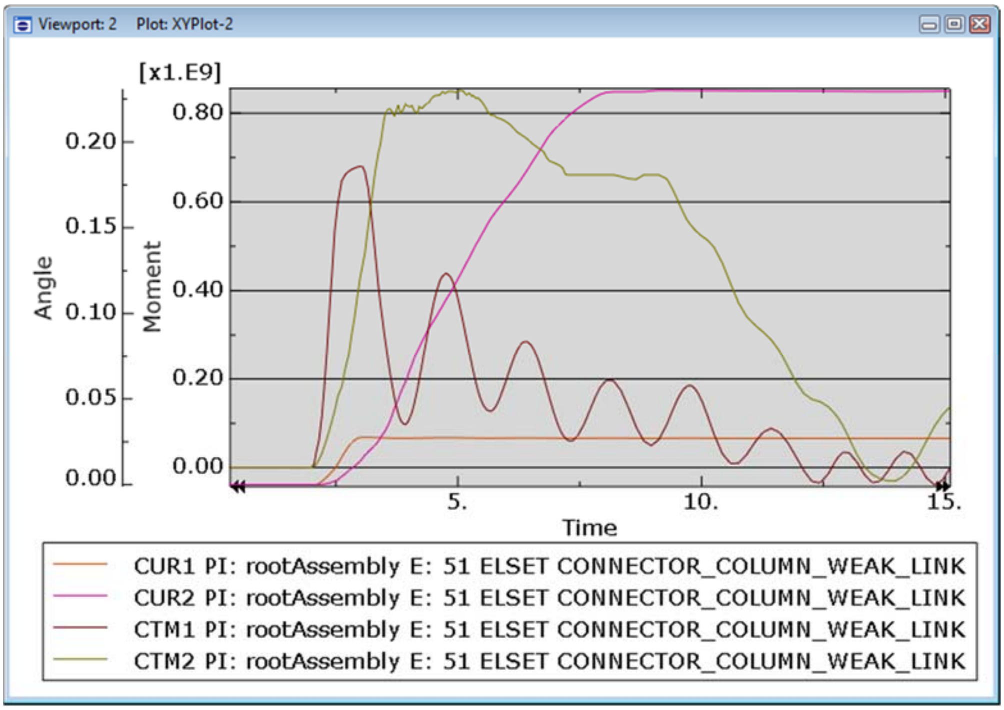




C.4.5 Extended results pontoon axis 3 – 90-degree eccentric impact

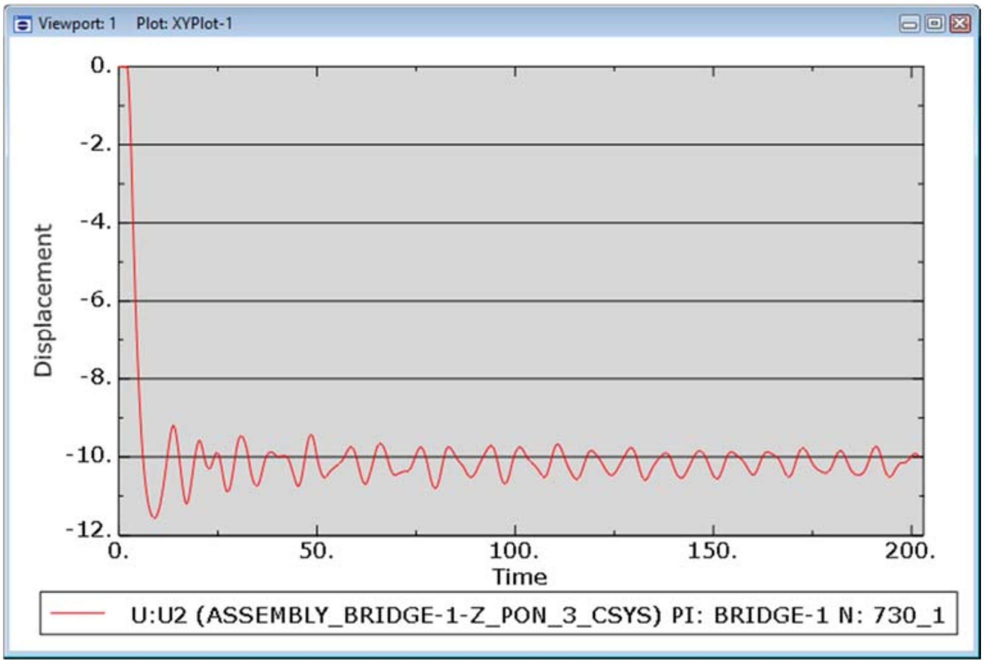
The 90-degree eccentric impact has been performed with a weak-link connector on the column top, for the plastic properties of a plastic hinge in the column top.

The weak axis bending (CTM2) and torsional moment (CTM1), together with the plastic rotations:



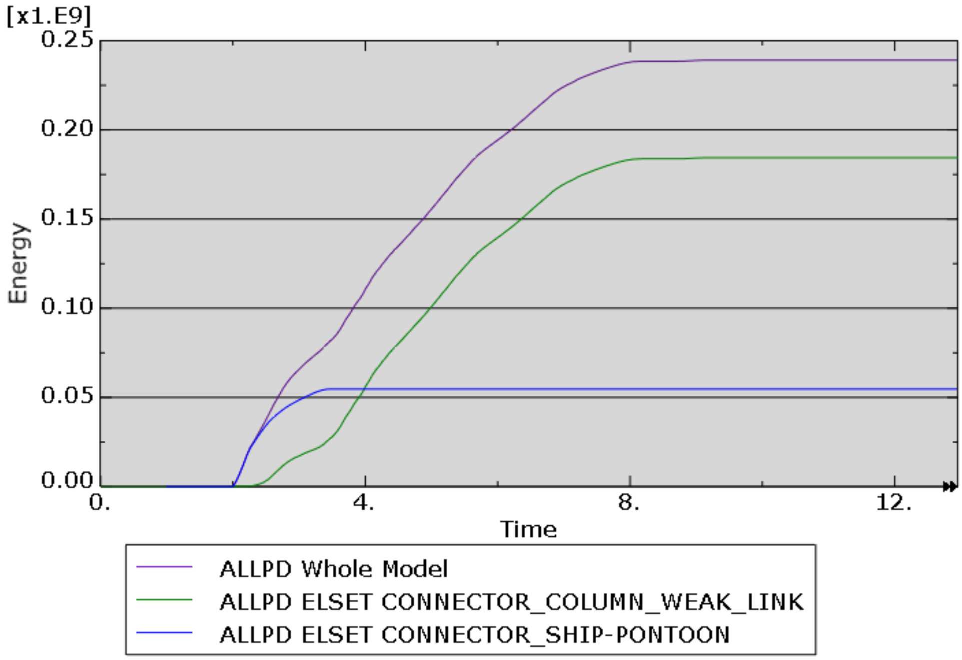
The plastic torsion evolves first, then the plastic bending leads to lower torsion. Plastic torsion rotation is 0,027 rad, while the plastic bending rotation is 0,23 rad.

The translation of the pontoon center during impact:



Total translation of pontoon center due to plastic rotations in column hinge is 10 m.

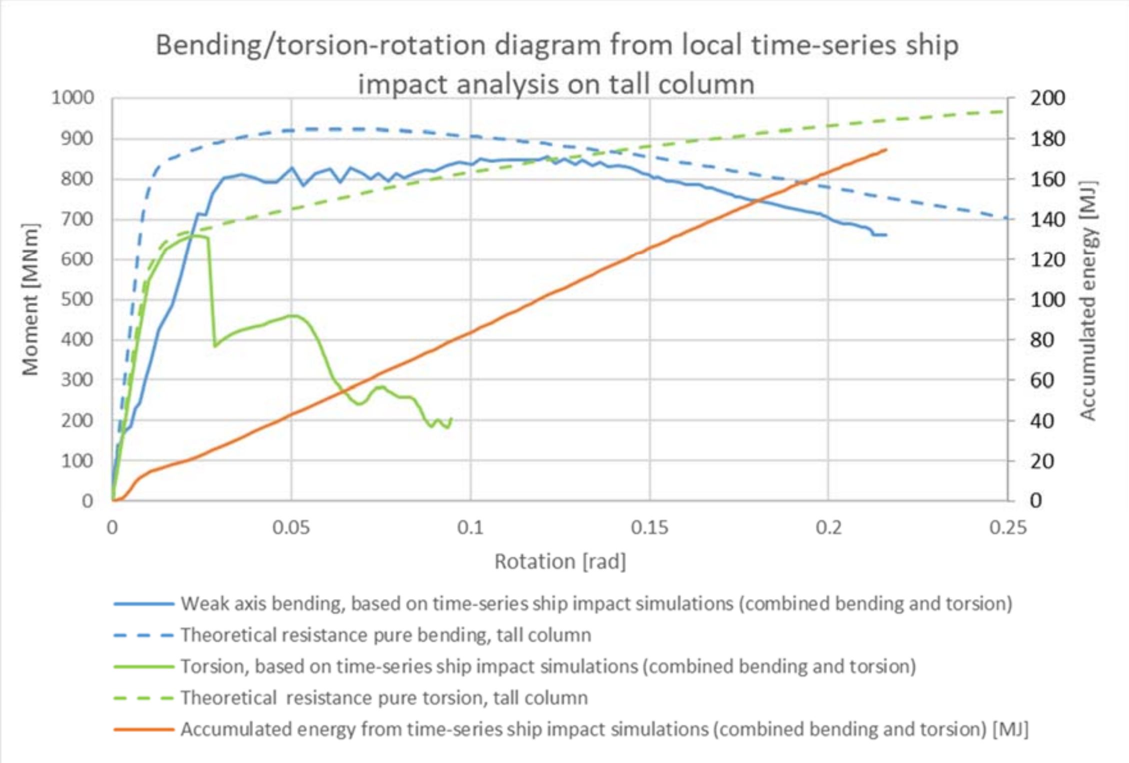
The distribution between plastic dissipation in the pontoon-bulb deformation and the plastic dissipation in the plastic hinge in column is shown below:



The plastic dissipation in the bulb-pontoon is 55 MJ, while it is 184 MJ in the column hinge.

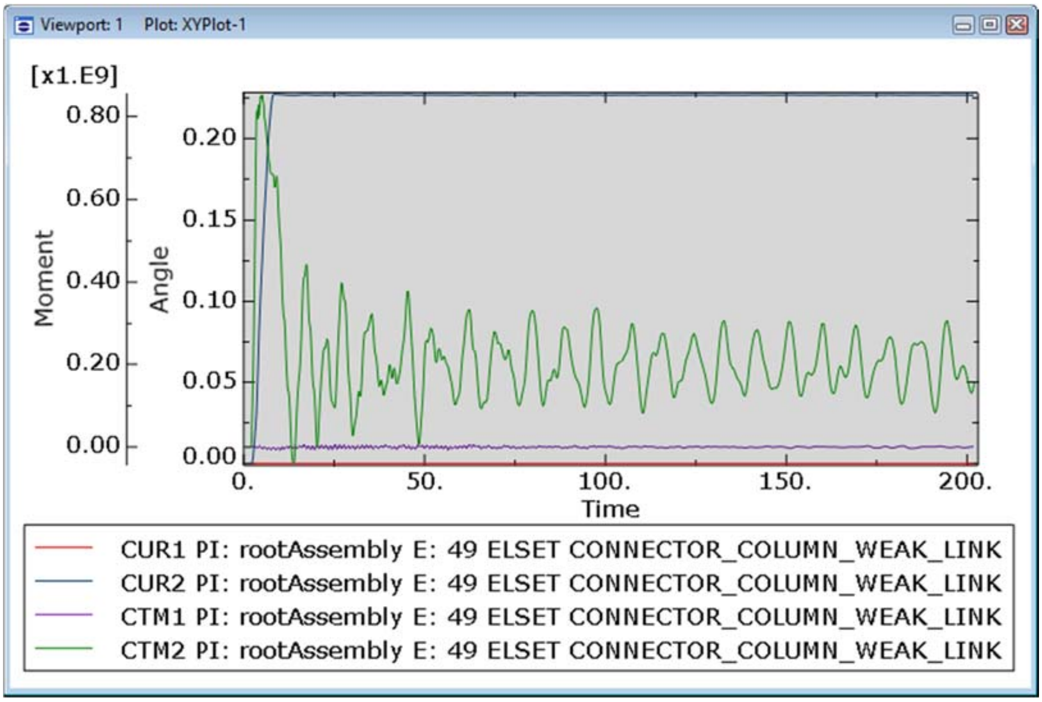
Compared to the time-series ship impact done in Appendix F the global model behaves quite similar, which is natural as it is based on M-phi-diagrams from these results. 184 MJ of plastic dissipation in the column hinge also tells that this detail is critically utilized and cannot take much more rotation. The column should be investigated closer in further work in order to obtain an even more ductile behavior.

The moment-rotation diagrams used in these analyses are shown below. They are from the results of the local analyses presented in Appendix F.



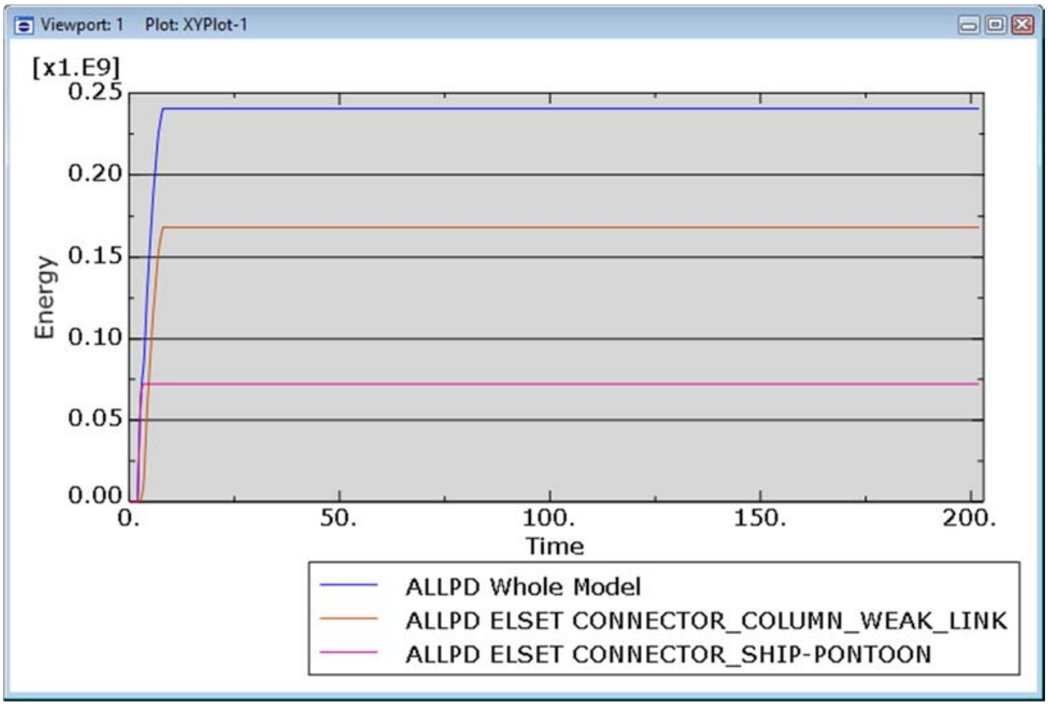
C.4.6 Extended results pontoon axis 3 – 90-degree centric impact

The weak axis bending and torsional moment is shown below, together with the plastic rotations:



The weak axis plastic rotation of the hinge is approximately the same as for the eccentric impact, 0,23 rad. This is due to a stiffer impact, which also can be seen in the distribution between plastic dissipation in ship-pontoon and in the column hinge.

The distribution between plastic dissipation in the pontoon-bulb deformation and the plastic dissipation in the plastic hinge in column is shown below:



1 REFERENCES

[1] SBJ-33-C5-OON-22-RE-014-B, «K12 - Ship impact, Pontoons and columns,» 2019.
[2] SBJ-33-C5-OON-22-RE-012-B, «K12 - Structural response analyses,» 2019.
[3] SBJ-32-C5-OON-22-RE-003-B, «Analysis method,» 2019.